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EVA SPACE SUIT EVAPORATIVE COOLING/HEATING GLOVE SYSTEM (ECHGS) FINAL REPORT

5 February 1976

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JSC 08774

PROJECT DOCUMENT COVER SHEET

FINAL REPORT

PROTOTYPE ACTIVE COOLING GLOVE
THERMAL TEST

REPORT NUMBER	DATE
CSD-SH-076	December 5, 1975

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NO. OF PAGES 17

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DATE	PREPARED BY	APPROVALS			CHG. LETTER
		BRANCH	DIVISION	PROGRAM OFFICE	

REPORT NUMBER CSD-SH-076

Review of contract NAS 9-14479's final report dated Feb. 5, 1976, revealed the following features of the program that should be recognized.

Page 1 - Reference is made to acceptance testing proving the thermal capability of the glove. This is not Governmental acceptance testing and the tests were conducted in air which is not realistic since the air tends to aid in thermal protection.

Page 3 - The report points out that the contract requirements were arbitrary values and that the values will be greater during a mission. This is not the case since the values have been used for other EV glove development successfully.

Page 6 - The contractor recommends fabricating the gloves with the seams external so the bladder lays against smooth surfaces. This is not practical because it forces the fingers to be more bulky.

Page 12 - It is pointed out that the glove developed holes in the bladder and that patches or other means of increasing the thickness is recommended, but on page 5 the contractor says 0.005" thick bladder is satisfactory.

Page 35 - The contractor discusses the testing of the NASA EV glove in comparison of their glove and points out that the NASA glove does not meet the contract thermal requirements. It should be pointed out however that the test was conducted in one atmosphere which eliminates the effectiveness of the glove's insulation.

Page 96 - The contractor spend a considerable period of time conducting test with one finger test samples and rolling the finger from side to side. This technique is not only not practical but when grasping something in the hand is impossible because the rolling function takes place from the elbow to the wrist.

Page 97 - The contractor reflects the above page 96 effort as possible but says they stopped the effort because of <u>NASA</u>. They do not address the lack of practicality.

Page 146 - The glove effort was insulated to protect the fingers and thumb only in specific areas. The palm and heel of the hand <u>are not</u> thermally protected.

Page 148 - It is pointed out that the inner glove is very critically sized and must fit properly. This will require custom fitted gloves for good performance.

Page 156 - Pressure testing of the glove at the contractor was from 2 - 4 psid only. No explanation was given as to why this was done at these pressures and why they varied between 2 and 4 psi.

Page 157 - The contractor states that the glove tactility and mobility is less than hoped but is deemed acceptable. This is only partially true as seen by the NASA review. The tactility and mobility are very poor and would not be acceptible for crewman use.

Page 157 - The weight of the glove is reported to be .638 pounds yet it must be kept in mind that this doesn't include the needed water injector that weighs about ten pounds.

Page 162 - The contractor points out that he ran tests using thermal patches that were evacuated but that he had to use .090 trilock as a space to accomplish the vacuum.
The trilock is a big insulator that is not part of the glove. ∴ temp and times are not valid.

Page 166 - The contractor points out that the inner glove should be kept on its stand and not handled or worn unless necessary for a test due to its delicateness. This does not lend it to being used for 7 hour EVAS and long periods of time for operational life.

The report did not discuss the results of the manned thermal vacuum testing conducted to any detail and therefore does not point out that the many bad features that were discovered during the evaluation. Ref. JSC 08774

- Freezing of fingers
- Long warm-up response time after activating water cooling
- Cooling of all of glove not just contact points
- Loss of sensitivity due to water boiling under fingers
- Quantity of water required for normal 7 hour EVA
- Sensing of all discreet points on glove with thermal control for cooling only the areas needed.

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1.0 SUMMARY:

The Prototype Active Cooling Glove Thermal Test was conducted July 8, 1975, in the JSC 2/20-ft chamber test complex. The test objective was to determine if evaporative water cooling could maintain a crewman's hand at an acceptable comfort level at the anticipated extravehicular temperature of 200°F.

A problem with the water injection system resulted in water going to the glove unmetered. This effect impacted the test results since the water was injected in varying quantities and therefore the length of the cooling period varied, at times longer than desired. A second problem was a pinched water line to the glove thumb area. This made the thumb of the glove unbearably hot.

The Active Cooling Glove Thermal Test demonstrated that, in its present configuration, an acceptable comfort level could not be maintained while gripping a rod heated to 200°F.

2.0 INTRODUCTION AND OBJECTIVES:

2.1 Background:

Extravehicular activities necessitate the wearing of thermal protective space suit gloves while performing tasks outside the spacecraft. These gloves protect the hands from impinging solar radiation and provide thermal conductive protection while handling hot and cold objects. In the past, this protection has been accomplished with significant loss of finger and thumb mobility and tactility due to the configuration and bulk associated with earlier passive thermal protective layups. The current active cooling glove supplied by water from inside the suit is an attempt at improving the finger mobility and tactility while maintaining an acceptable comfort level with the glove while handling objects with a surface temperature of 200°F.

2.2 Objectives:

The objective of the Active Cooling Thermal Tests was to determine if evaporative water cooling could maintain the crewman's hand at an acceptable comfort level under the anticipated extravehicular thermal environment of 200°F.

3.0 TEST ARTICLE DESCRIPTION:

The active cooling glove, in its present configuration, incorporates a bonded urethane bladder, a Kevlar/Nomex woven material restraint, an intermediate layer of Kevlar/Nomex, two layers of perforated aluminized Kapton film and an outer layer of woven Kevlar/Nomex material. The Kevlar/Nomex layers act as wicking layers to distribute cooling water over the surface of the glove. The Kapton layers, in effect, form a permeable pressure barrier to maintain a slight pressure on the water, thus controlling the rate of evaporation. When the water evaporates at low pressure, heat (equivalent to the heat of vaporization of the water) is removed from the glove and hand.

The glove bladder was bonded with an urethane cement and the restraint was stitched. The assembly was mounted to a wrist bearing/disconnect which had an integral vent duct. The palm restraint was a typical metal restraint attached with small webbing.

A water feed system was provided with the active cooling glove which flowed water by manual actuation of a water injector device.

4.0 FACILITY DESCRIPTION:

The Active Cooling Glove Thermal Test was conducted in the JSC 2/20-ft diameter chamber test facility (Figure 1). The outer manlock of the 20-ft chamber provided a crewman access to the inside of the glove at 4 psia while the 2-ft chamber, attached to the wall of the outer manlock, provided the desired exterior environment for the glove. The glove was connected to a suit wrist-disconnect fitting attached to a bulkhead plate between the two chambers. A total of three crewmen took turns evaluating the glove.

The manlock and 2-ft chamber can be operated independently of the main 20-ft chamber and each other with the exceptions that the main chamber must be at a lower pressure than the lock and that the glove must be isolated from the lock if the lock pressure is 4 psi greater than the 2-ft chamber pressure.

The 2-ft chamber vacuum system was capable of reducing chamber pressure below 5×10^{-1} mmHg for this test configuration. A shroud on the inside periphery of the chamber could be controlled at temperatures over the range of -300 to +300°F. A 1-1/2-inch

diameter tube was located in the chamber in a position to be gripped by a crewman whose hand was in the glove. The temperature of this tube could be controlled over the range of -300 to +300°F.

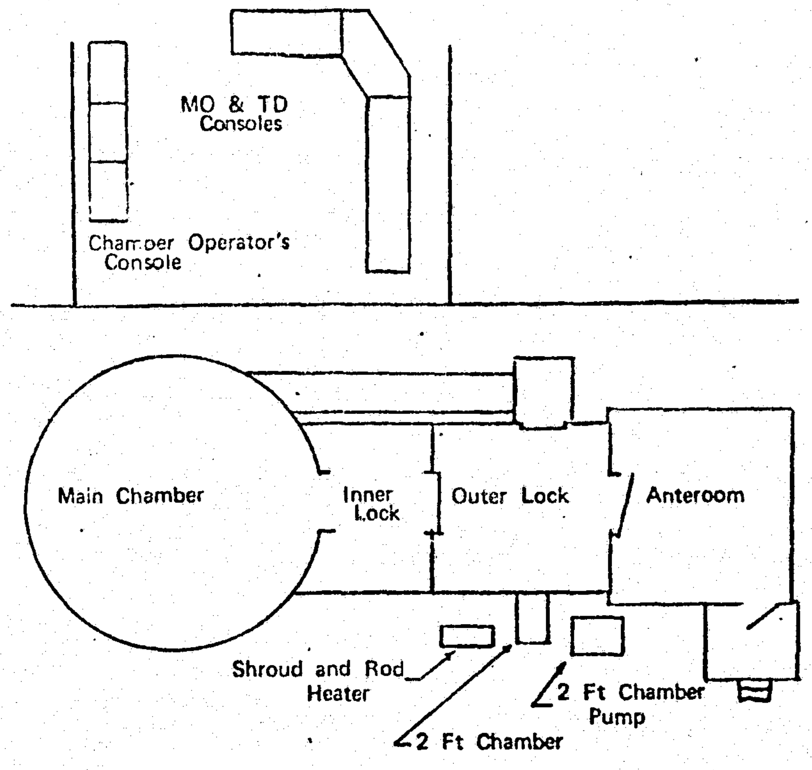
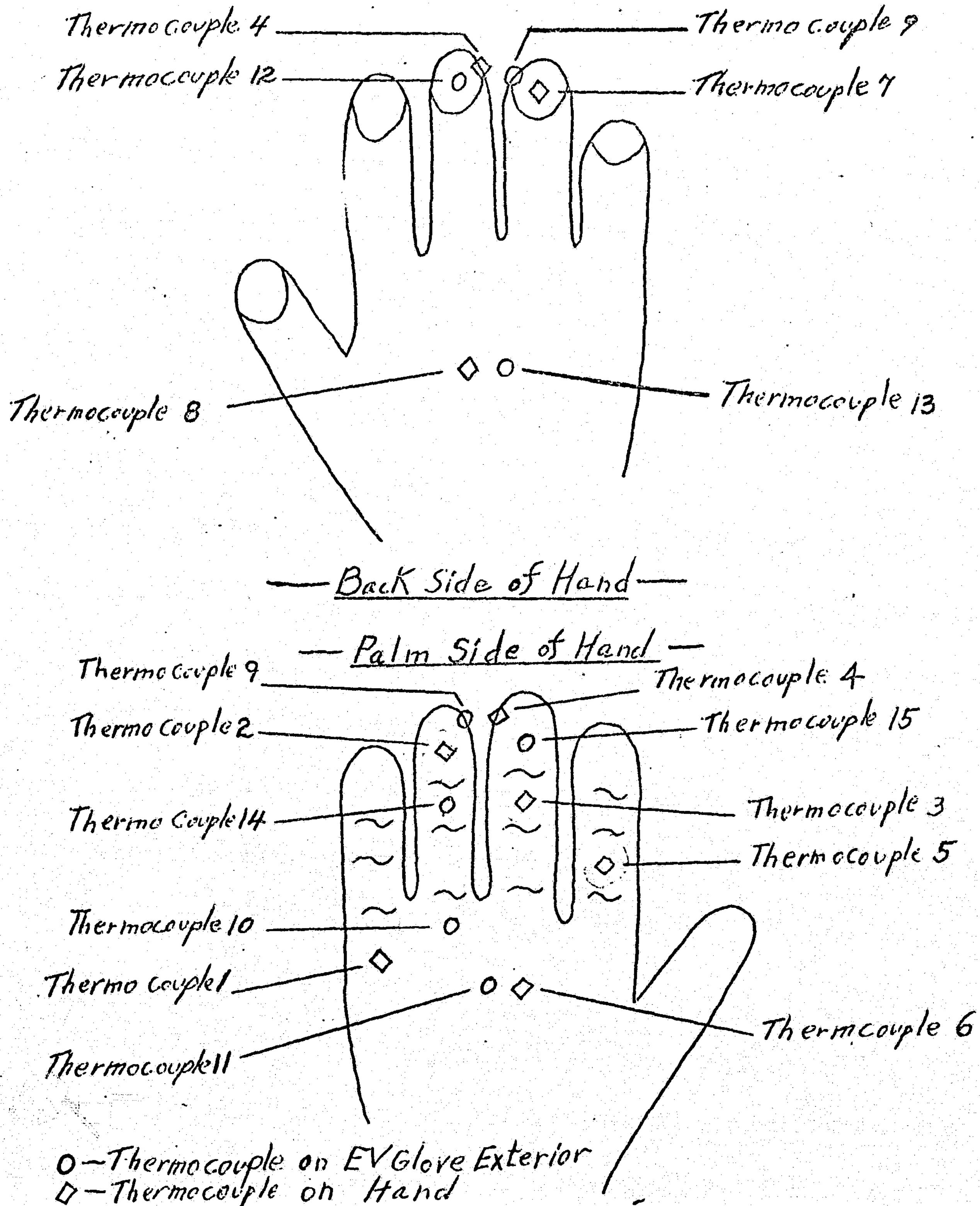


Figure 1 - General Chamber Layout

The 20-ft chamber outer manlock is equipped to provide breathing oxygen and communications for three crewmen on O_2 masks at pressures below ambient. A closed-circuit television system provides test team members with a view of activities in the manlock. A swinging seat and a grip-rod with a 12 pound counterweight had been installed in the manlock to assure that each crewman would grip the rod in the 2-ft chamber with a consistent force. A pump, flowmeter, and a controller were attached to the glove vent duct to draw 1.5 cfm ventilation flow through the glove.

5.0 TEST EQUIPMENT SCHEMATIC



TEST EQUIPMENT SCHEMATIC, CONTINUED

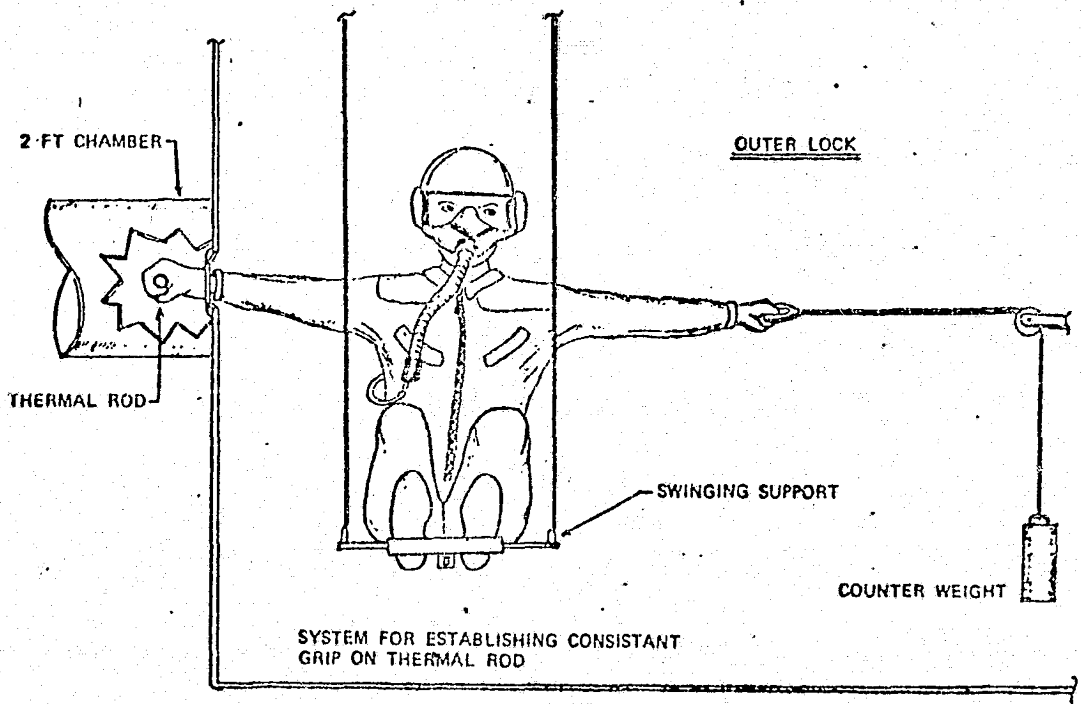


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Figure 2- Grip Rod Loading System

6.0 TEST DESCRIPTION:

This test was conducted to demonstrate the performance of a spacesuit glove which incorporated an active thermal control system utilizing the water boiler principle for heat removal.

The data discussed here resulted from tests conducted with the glove in a vacuum chamber and worn by a variety of test subjects who used the glove to grasp a 1.5 inch diameter aluminum jacketed stainless steel thermally controlled rod to effect a thermal transfer source or sink. The tests were run with the rod at, nominally 200°F, and the rod was grasped in a manner to assure a surface loading of at least 12 pounds force at the areas of contact.

The duration of each run was determined by the test subject. Hand release was enacted at nominal discomfort of localized areas of the hand, with a goal of 3 minutes duration. The test data does not include the thumb due to a failure of the water distribution system in that area (crimped tube). The test subjects consciously avoided thumb contact with the thermal rod to enable the test to continue.

7.0 ANALYSIS OF TEST RESULTS:

The first gripping of the rod is depicted in Figure 3. The crewman was able to grasp the rod for 1 minute 21 seconds before he had to release it, when the hand temperature reached 109°F. Interestingly the external glove temperature dropped 125°F in 8 seconds (thermocouple 15) as the coolant water was exposed to the vacuum environment.

Finger temperature (thermocouple 41) slowly increased to 109°F, while finger temperature (thermocouple 38) slowly decreased to 81°F. Operationally this variation of 28°F would be unacceptable and indicates a need for uniform temperature control.

During the second gripping, with crewman #2 (Figure 4), more uniform cooling was achieved. This gripping demonstrated that a single injection of H_2O can maintain cooling for over 3 minutes. The skin temperature here decreased from 96°F upon grasping the rod, to stabilize at 60°F to 70°F.

Gripping number three was aborted due to the inability of the third crewman to prevent his thumb from contacting the rod and the resulting painful skin temperature.

A broad skin temperature variance occurred during the 2 minute 41 second duration of gripping number four (Figure 5). One finger temperature reached 46°F while another climbed to 114°F. Moreover upon release of the rod the temperature response time to reachieve an equalization temperature was lengthy, indicating there may exist a temperature response control problem. Although no thermocouple was installed on the glove index finger to indicate temperature there, the relatively slow temperature increase of thermocouple 41 on the skin of the crewman's index finger indicated either insufficient water supply or very light index finger contact with the rod or glove.

The thermocouple 38 plot indicates that in general areas of water availability, evaporation effectively forces the glove local temperature to drop. However, the area adjacent to thermocouple number 36 apparently did not receive adequate water, since a significant decrease in temperature did not occur there. This data indicates that there was uneven or inconsistent distribution of water to the fingers.

Gripping number five, which lasted for 3 minutes and 18 seconds, (Figure 6), demonstrated similar performance to gripping number four, with large temperature variations between fingers.

An undesirable phenomenon was experienced by all three crewmen who commented that they could feel the water boiling between their fingers and the rod which they gripped. They stated that the boiling felt like "hundreds of small beads vibrating under the fingers," and it was difficult to feel the rod since the boiling disguised the surface. This condition would effectively destroy sensory feedback and tactility enhancement being sought in this program.

8.0 CONCLUSIONS AND RECOMMENDATIONS:

8.1 Conclusions:

The performance of the evaporatively cooled glove revealed serious deficiencies that apparently can only be overcome by extensive redesign or a decision that active cooling using the evaporative cooling approach is not feasible for glove application.

These tests accomplished little more than reproving a well established principle that sublimation of ice or evaporation of water in a vacuum is an effective way to remove heat (reference performance of Apollo CM water boilers and PLSS and LM sublimators). The performance here did demonstrate an ability to prevent excessive heat flow into the hand and an effective response for

quickly lowering temperatures of surfaces exposed to high heat inputs. However, a primary purpose and design constraint of thermal protection for the hand is to provide a degree of thermal comfort without unduely affecting required tactility and mobility for performance of extravehicular functions.

A primary concern that surfaced during the tests was the lack of control of cooling rate during active heating stimulus and, importantly, the slow response time to deactivate the cooling system after the stimulus had been removed. In effect, the system is either always all on or all off, providing maximum cooling in all areas regardless of demand. It is suspected that in this case maximum cooling could have resulted from both the evaporation of water (boiling) and the sublimation of ice that formed in discrete areas. (The data supports conditions favorable for ice formation.)

The net result was that extreme discomfort and dangerous sub-cooling of the hand occurred (at times) throughout the tests since not all areas were in equal contact with the heat source, and the act of releasing the heat source allowed the hand to continue to be cooled to the evaporation temperature of the water. Thus the system exhibited inertia and poor warmup response time due to residual water remaining after the heat stimulus was removed. Shorter response time will be required. In order to achieve the short response times critically necessary when grabbing or releasing a heat stimulus, sophisticated and elaborate sensing, control, and distribution systems seem to be in order. This may be dictated due to the complex shape and functions of the hand where the external heat loads are never steady state, vary radically across small areas, and cannot be easily transferred from one region to another due to small thermal mass and discontinuous surfaces.

Thus, a large number of discrete cooling regions with independent sensing and cooling controls could be necessary to assure proper area cooling and time response. This would be necessary to compensate for large variations in cooling demand brought about by hand geometry which may dictate large cooling required by an intense heat input in an area that may be adjacent to an area which is not in contact with the heat source and requires little active cooling.

It can be concluded that the proper amount of water injected is very critical to assure comfort during the gripping time and immediately after release. This is evidenced, somewhat by the randomness of the gripping times from run to run, the temperature profiles achieved, and subjective comments on comfort.

8.2 Recommendations:

The thermal control system tested here is not suitable for application to space suit extravehicular gloves in its present configuration. Extensive redesign and associated additional funding and time would be required to achieve acceptable performance through development of the necessary sensing, control and distribution systems that seem to be indicated. Control could be effected either through precisely controlled injection quantities to many discrete areas, or through regulating the boil off/heat injection rate by back-pressure regulation. The former control technique could require an extensive and complicated distribution network, and both methods could require an elaborate sensing system with associated logic controls that responded to heat load demands. The water injector delivered with the system would require redesign since it does not address the above problems, it is not compatible with the space environment, and is not effectively adaptable to EVA space suit use due to poor weight, bulk, and reliability factors.

The extreme simplicity of this technique and its effective performance for extremely rapid cooling rates, could make it attractive for applications where larger, more uniform surface areas not constrained by human factors design are available, and where a more uniform heat flux is imposed. Such applications do not require the rapid response times or the precise controls that seem to be dictated for glove applications.

APPENDIX

ABSTRACT

The astronaut's work environment, particularly during EVA requires the handling of objects to + 200°F and - 200°F. A new glove, the Evaporative Cooling/Heating Glove System (ECHGS), has been designed and developed by Environmental Research Associates, Canoga Park, California to meet these limits. Active heating elements, positioned at each finger pad, provide additional heat to the finger pads from the rest of the finger. A water evaporative cooling system provides cooling by the injection of water to the finger areas and the subsequent direct evaporation to space. Thin, flexible insulation has been developed for the finger areas to limit thermal conductivity. The complete ECHGS uses the O.E.S. S/N 001 Kevlar outer glove and related standard wrist ring for astronaut suit attachment.

Component and full glove tests have shown that the glove meets and exceeds the requirements to hold a $1\frac{1}{2}$ inch diameter bar at ± 200°F for three minutes within comfort limits. The ECHGS is flexible, light weight and comfortable. Tactility is reasonable and small objects can be identified especially by the fingertips beyond the one half width active elements.

The ECHGS is ready for pre-production development. Significant elements of a suggested program are presented in the Recommendation section of this report.

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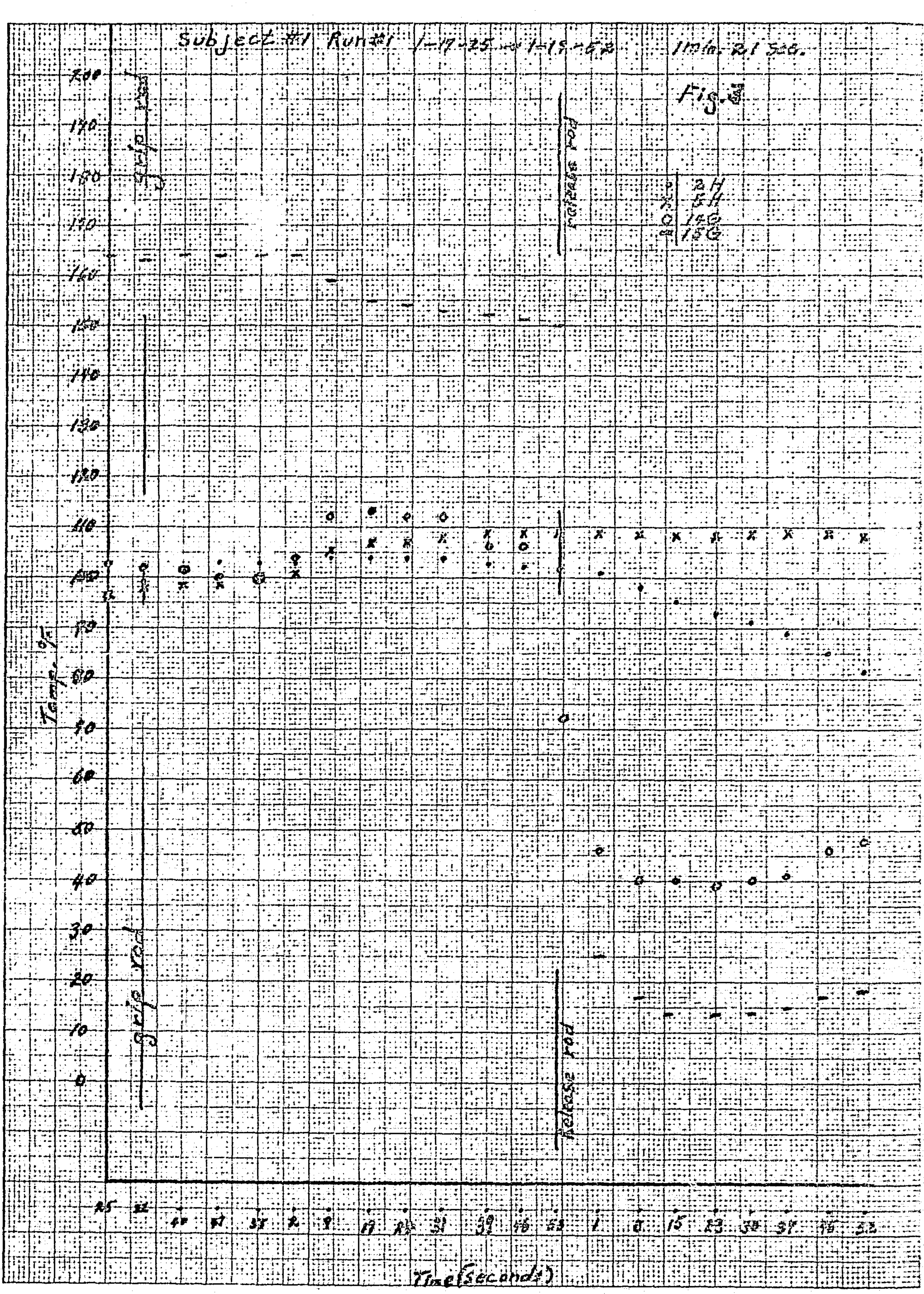
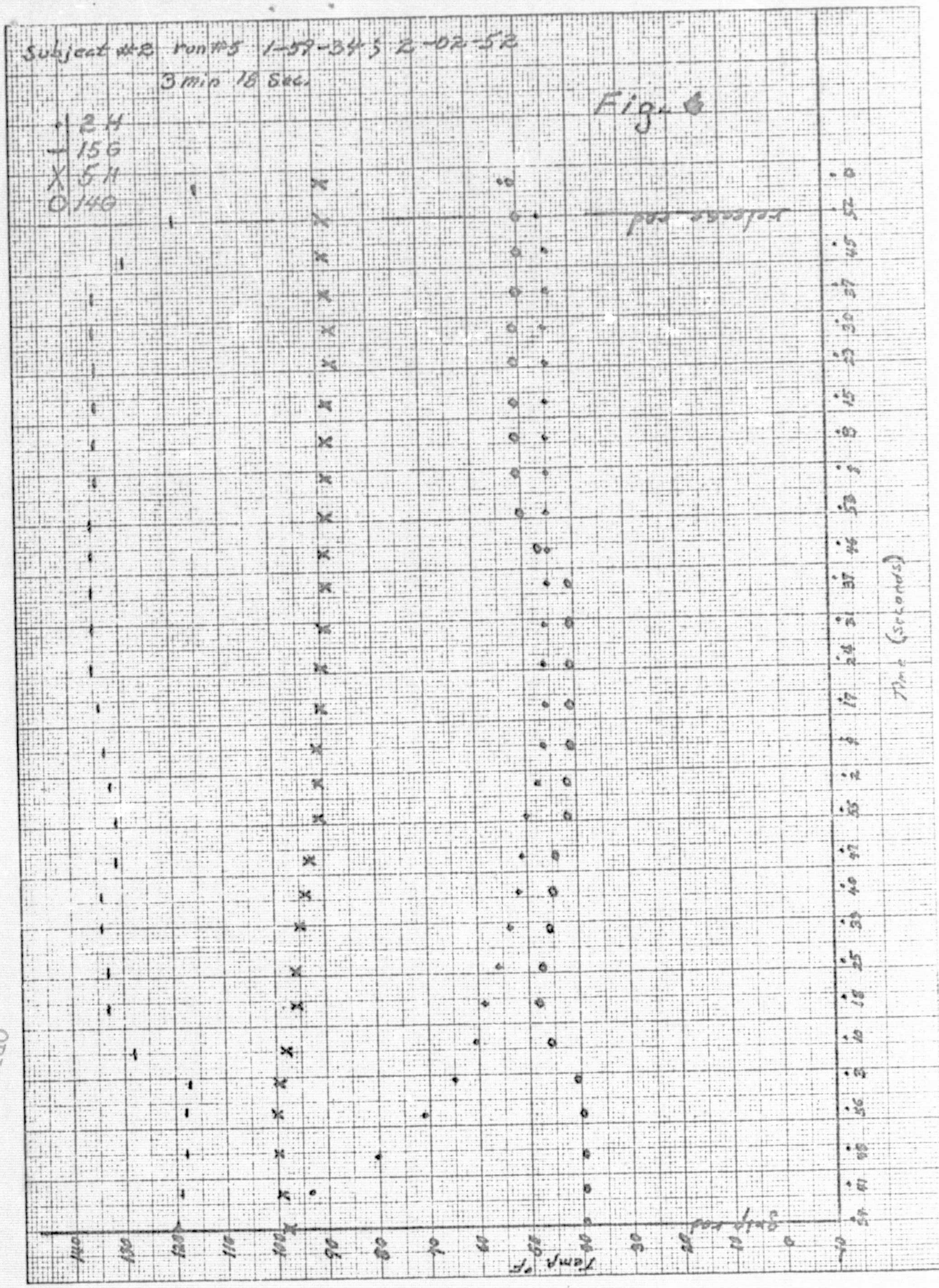
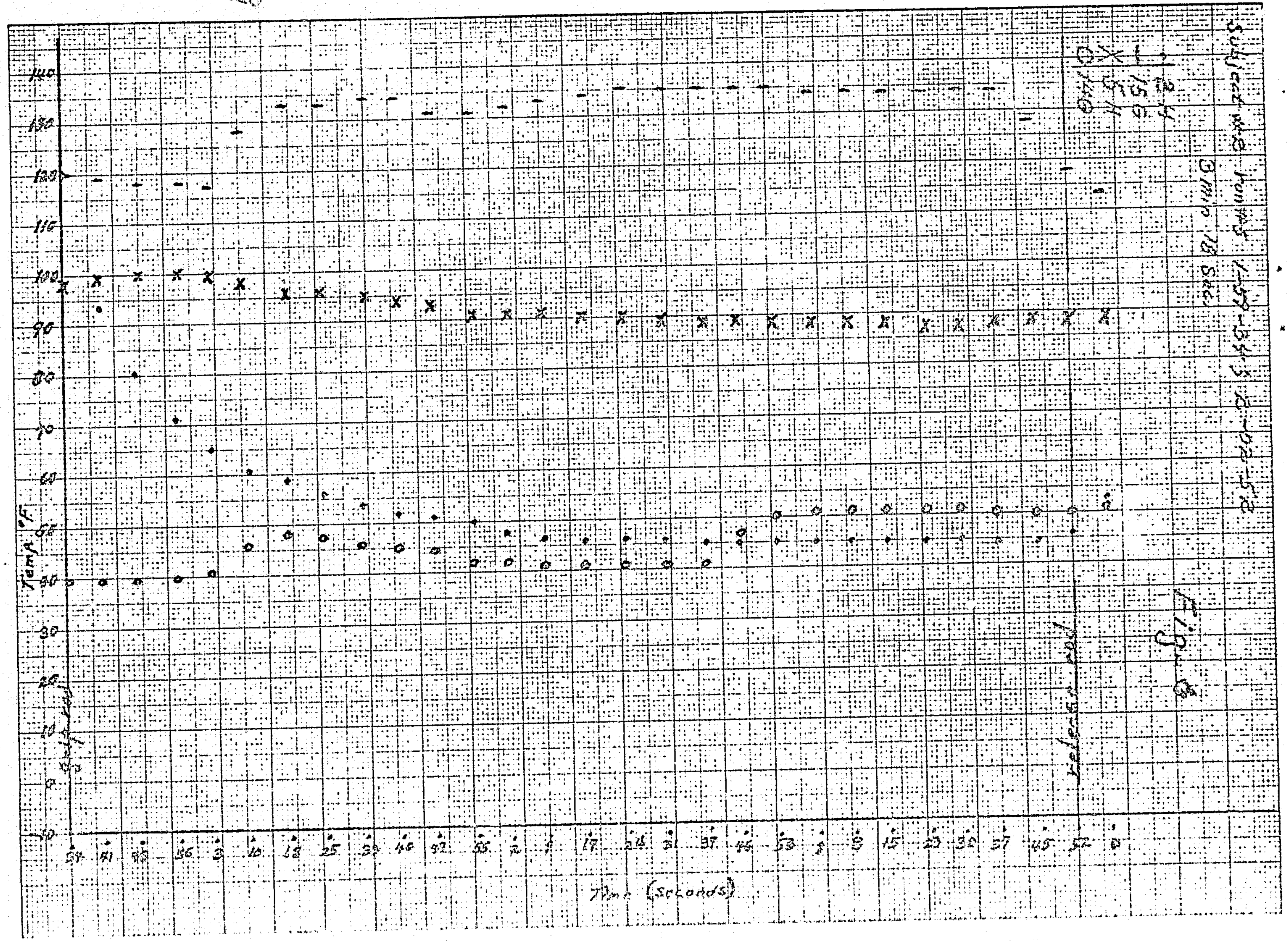
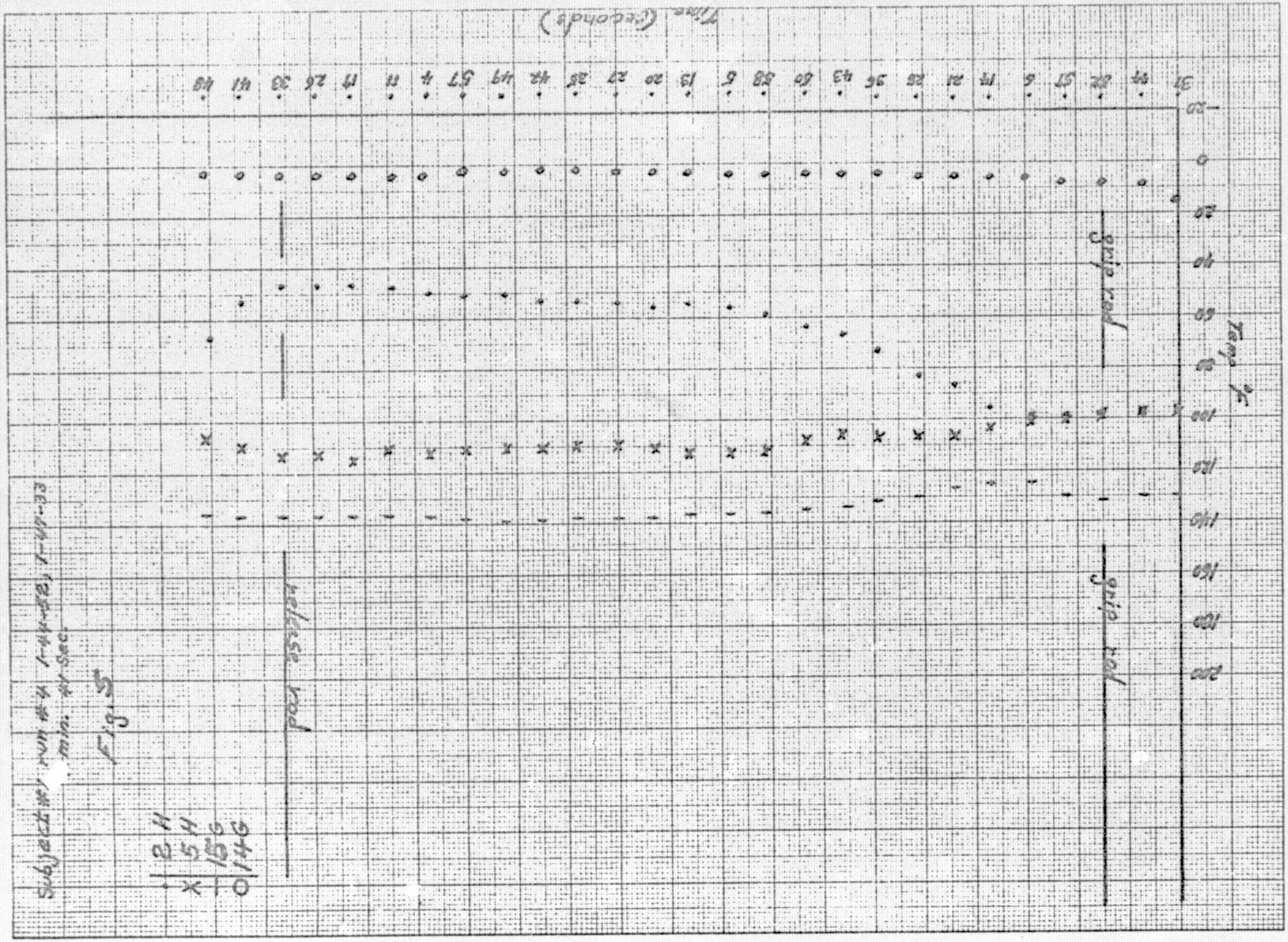
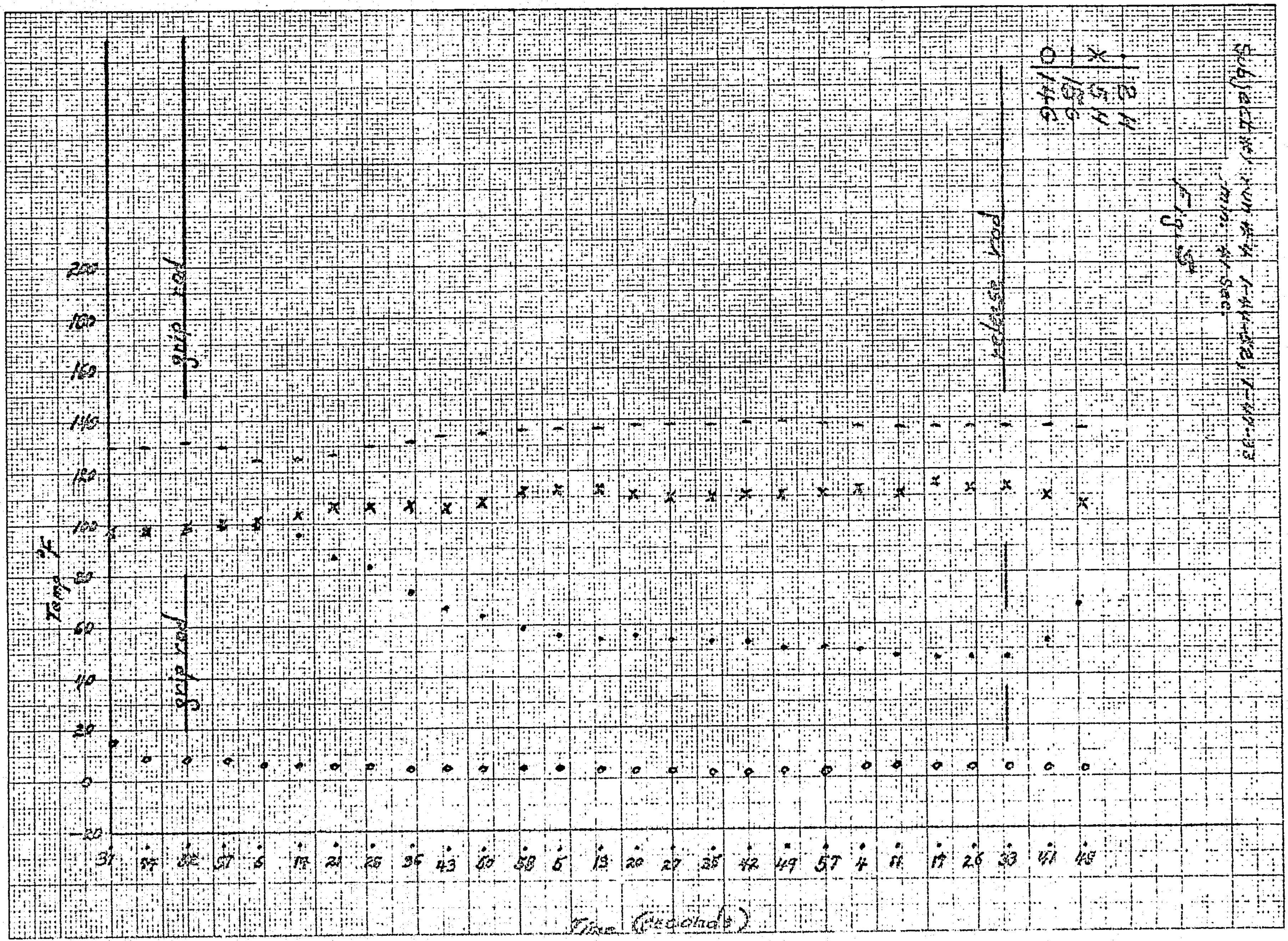


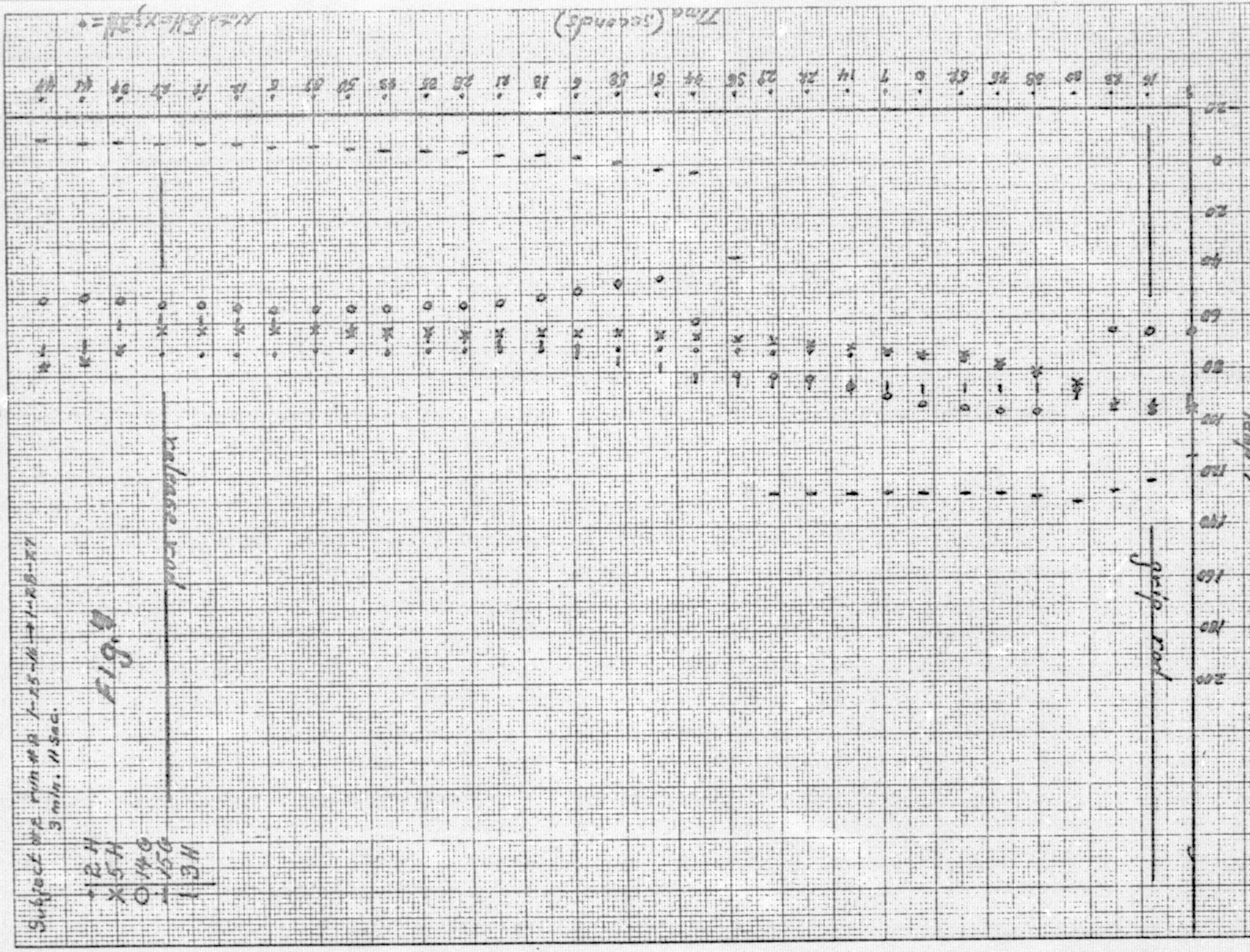
Subject #1 Run #1
Fig.
grip rod
release rod
Temp. °F
Time (seconds)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


Subject #8 run #5 1-59-34.5 2-02-52
3 min 18 Sec.
• 24
— 15G
X 5H
O 14G
Fig. 6
release rod
grip rod
Time (seconds)
Temp °F


Temp °F
Time (seconds)


Subject #1 run #4 1-44-52, 1-47-33
min. 41 sec.
Fig. 5
• 2 H
X 5 H
– 15 G
O 14 G
grip rod
grip rod
release rod
Temp °F
Time (seconds)


Subject #4, run #4
Fig. 5
release load
Temp °F
200
180
160
140
120
100
80
60
40
20
0
-20
Time (seconds)



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DEFINITIONS

A few abbreviations have been used in the text, these include:

ERA	Environmental Research Associates The contractor on this program.
ECHGS	Evaporative Cooling/Heating Glove System
ECGS	Evaporative Cooling Garment System
EVA	Extra Vehicular Activity
RTD	Resistance Temperature Determination
GFE	Government Furnished Equipment
SCC	Standard Cubic Centimeters

INTRODUCTION

Environmental Research Associates (ERA) originally submitted an unsolicited proposal to NASA for the Evaporative Cooling/Heating Glove System (ECHGS), as applied to the Shuttle Program in March 1973. This was followed by a solicited proposal, Request for Proposal No. 9-BC76-81-4-95P, for the development of the ECHGS for the Extravehicular Space Suit in March, 1974. In February, 1975 contract NAS 9-14479 was awarded ERA for the development of Improved Extravehicular Space Suit Thermal Gloves.

Under this contract, ERA has conducted studies and analyses, fabricated components and prototype glove components and performed component and full glove tests leading to the acceptance tests. During the acceptance tests the glove heating capabilities were proven. The water evaporative cooling system was demonstrated in July at Houston on the prototype glove. Slight modifications to the cooling system have been made, (to reduce the cooling rate), as a result of those tests and the final glove incorporates these changes.

The ECHGS is made in two sections, the inner glove assembly and the outer glove assembly. The inner glove assembly incorporates fourteen active finger pad heating (and cooling) elements integrated into the comfort glove (GFE). The outer glove assembly incorporates the water evaporative cooling water distribution system, the finger and thumb insulation pads and a rubber pressure membrane. These components are all assembled to the O.E.S. S/N 001 Kevlar material outer glove and related aluminum wrist ring (GFE).

The acceptance tests of the complete ECHGS showed that the major objective to the program, namely to be able to hold a $1\frac{1}{2}$" diameter bar at $\pm 200^{\circ}$F for three minutes, has been met or exceeded.

CONCLUSIONS

The Evaporative Cooling/Heating Glove System (ECHGS) has been analyzed, designed, fabricated and tested under this program. The evaporative cooling system provides adequate cooling to meet the + 200°F for three minutes within finger comfort limits. This system can readily meet greater time and/or higher temperature limits. The demonstration water injector assembly must be replaced with a flight type unit. The active heating elements meet the -200°F for three minutes operational limits within comfort limits. The rubber membrane supplied with the ECHGS is considered satisfactory for ground tests. However, the use of urethane or a similar material has been recommended for the production gloves. The ECHGS comfort and tactility are good, but optimum comparisons cannot be made since the (GFE) outer Kevlar glove is too small for the best fit with ECHGS components, even for the subject used (smallest hand available). Both the water system and glove membrane were void of leaks. The ECHGS glove proper weighs 289.2 grams compared to 600 + grams for the work glove and the Schweickart glove. The final design water injector assembly weight must be added to obtain the full system weight, however.

The ECHGS with the demonstration water injection unit fulfills the contract requirements.

RECOMMENDATIONS

This contract has produced a glove which will meet the $+200^{\circ}$ F and the -200° F temperature limits while holding a $1\frac{1}{2}$ inch diameter bar for three minutes. Naturally, these limits were arbitrary and were intended to provide goals for this initial contract. However, in the actual EVA missions longer contact with hot and cold objects will be commonplace. Also, the need for handling tools, relatively small fasteners etc., creates increased requirements for the production ECHGS. It is recommended that a substantial pre-production program be conducted wherein these increased requirements become the new goals. Although the details for a long EVA mission of the future are not fully understood by Environmental Research Associates, certain aspects such as longer time exposures are rather obvious. Accordingly, the following detailed items are suggested for inclusion in the pre-production program.

Water Injection System

As noted elsewhere in the report, the water injection system supplied for use with the ECHGS, under this contract, is a demonstration unit only. If the external evaporative cooling system (directly to space) is retained for the cooling of the Production Gloves, a miniaturized injector design which is fully compatible with the overall astronaut suit is required. ERA has a series of ideas related to a new overall design. These can be discussed in detail at a later date. The design would involve optimized storage volumes, miniaturized components, would be devoid of cams and related items which made the demonstration unit a viable design for the purposes under this contract. Minimum weight and spatial requirements with maximum reliability which would include

redundancy would be major objectives. The pre-production development of a final design water injector is an absolute must for full operation of the ECHGS.

Active Heating (and Cooling) Elements

The copper elements included in the final ECHGS are operationally satisfactory to meet the requirements of the contract. The complete EVA requirements, as delineated by NASA, will undoubtedly increase the requirements for the ECHGS. As noted by the data obtained during this contract, the satisfactory operating time for the glove while holding $\pm$ 200° F objects often exceeded the 180 seconds minimum contractual time. The active elements, as designed and fabricated for the ECHGS were not optimized for the best heat transfer to meet harsher requirements. The use of silver instead of copper would provide 10% improvement in heat transfer. The possibility of using either silver or silver-plated copper (to prevent corrosion, in particular) will be looked into during the new program. Improved retention of the element wires, possibly by intermittent line plating, could possibly permit direct finger contact on the sides and tops of the fingers with the attendant improvement in heat transfer. The comfort glove might be slotted to permit the active element to pass out from the side of the finger, next to the finger pad, and return to the other side thus allowing the glove positioning of the element and to provide some added local insulation.

The success of the active elements in transferring heat from the entire finger circumference to the finger pads indicates that a full inner glove made of heat conductive material may be more efficient than the use of individual finger elements. The use of localized heavier sections, such as the finger elements designed during this program, in addition to the

complete active glove may be desirable. Accordingly, it is recommended that the use of a glove knitted from silver or copper wires be considered. If basic consderations permit, an overall design should be made and the glove knitted by a glove manufacturer. Localized elements, if desired, would be added by ERA. Extensive heating (cold work items) and also cooling (hot work items) tests would be made to determine the improvement. An objective would be to see if adequate finger cooling could be accomplished so that the evaporative cooling could be eliminated. The use of an emergency, single shot, syringe bulb supplied water would simplify the overall ECHGS.

Pressure Bladder

The pressure bladder should be made of molded urethane. Experience indicates about a .005 inch thickness should be satisfactory. However, the sizing of the bladder is important. It should be very slightly oversize compared to the inflated inner dimensions of the outer Kevlar retaining glove. The possibility of the GFE urethane bladders, on this program, having been smaller than the outer Kevlar glove may have led to installation stretching and material failure by strain beyond the material elastic limits. The molded urethane bladder should be thickened in the attach band area to the wrist ring. Tests should be conducted and the determination made whether thickened areas should also be made at the fingertips. Integral tabs for retention of the tips in the outer glove should also be considered to provide improved, low strain retention. The possibility of secondary retention of the bladder to the outer glove, such as on the back of the fingers at the base of the fingers, should also be examined and tested.

Outer Kevlar Glove

The O.E.S. S/N 001 Kevlar Glove is light in weight and appears to be a sound, structurally adequate outer glove component. However, the basic characteristics of Kevlar indicate some design changes should be considered. The multiple rough edges of the inner surface of the Kevlar glove, particularly those treated with Edgelock sealer, may well be sources of membrane failure. Consideration should be given to two design changes. First, make the glove inside-out from the current method, i.e. all seams and sharp edges on the outside of the glove and a smooth interior. It is recognized that the glove would not look as good when designed in this manner but the reliability of the overall assembly would undoubtedly be improved. Second, if the first design change suggestion can not be accepted, provide a rubberized seal over all loose ends of Kevlar and seams. This would provide a cushion for the membrane material to seat against.

The use of steel, in the palm area, for the reinforcing of the glove may not be necessary or as good a material as braided Kevlar. It is noted that the tension ties to the wrist ring have been made of Kevlar on the O.E.S. S/N 001 glove whereas the earlier glove design employed steel cables. The Kevlar ties appear to perform well and yet have good flexibility which the steel does not. The S/N 001 cross bar is too narrow for the ECHGS, particularily in the little finger area. This makes donning a greater problem. It is recommended Kevlar be considered for all pressure holding reinforcing. In any event, if steel must continue to be used, a wider cross piece at the palm is needed.

Glove Water Distribution System

The glove water distribution system is about as simple as it can be, as

designed for the ECHGS. However, the system is comprised of brass parts mainly. These were chosen as off the shelf fittings and as an expedient in fabrication. The use of anodized aluminum is recommended for the production glove. A minimum of potential leak paths should be permitted by the maximum use of machining from a single piece. The basic design of the ECHGS is considered satisfactory except that axial outlets from the manifold to the fingers are suggested. The pressure membrane support shield may possibly be integrated with the manifold. This should be investigated.

Glove Insulation

The ECHGS insulation is considered satisfactory to meet the contract requirements. However, the overall EVA missions may require additional protection. Insulation for the back of the hand will probably be required. This insulation should be separate from that used on the fingers; perhaps having loose overlap sections to provide the best flexibility. The thermal resistance will no doubt differ from that for the fingers so the design should be carefully worked out in accordance with the requirements.

A major problem exists in the testing of glove systems, particularily in the cooling mode in that good vacuum levels are hard to obtain. This is mainly due to high vapor pressures of the constituent materials. A continuation of the materials review made in conjunction with designing the ECHGS is required. Tests at ERA showed that Kevlar, particularly with Edgelock treatment had a high vapor pressure at +200°F. The comfort glove material also outgassed considerably. Although the outgassing of these glove materials will present no problem when used in space the use of lower vapor pressure materials will assist the testing and development here on the earth.

Evaporative Cooling

The evaporative cooling developed for the ECHGS is the "direct to space" type system which requires controlled injection rates. This system also cools at a maximum rate (to 32°F) and the water freezes upon evaporation and it later sublimes thus extending the cooling period. These problems may make it worthwhile to re-examine the use of the Evaporative Cooling Garment System (ECGS) for the glove. Please refer to References number 4, 5, and 7, also refer to the ERA proposal leading to the current contract. The ECGS allows temperature control from hand temperature to 35°F by simple valve settings to control the boiling point of the water in the system. The rate of cooling can be very high and water freezing and excessive cooling rates are avoided. Use of the ECGS for the glove involves the design and development of flexible vacuum tight units, perhaps individual finger pad size. Compatibility of this cooling system with the heating system would have to be assured. The water supply means for the ECGS is simpler than that needed for the current ECHGS. It is therefore recommended that the ECGS be re-examined in conjunction with the further development of the ECHGS active elements as presented herein.

ECHGS Development Tests

The recommended pre-production improvements, plus those ideas which NASA undoubtedly has, requires a substantial development test program. This program should include all the necessary component testing leading to full glove testing. The final proof tests should include as complete an EVA (as anticipated for future work) as possible. To this end, testing both at ERA and at Houston is suggested. The possibility of using Air Force vacuum facilities at Edwards Air Force Base or other government facilities close to ERA should be examined.

The overall program, of course, can only be delineated after the full pre-production development is established by NASA and ERA.

DISCUSSION

The work under this contract has been quite extensive and has covered several important areas. For ease of reading and the compilation of the more pertinent data under meaningful headings, the work has been separated into several categories:

GFE Equipment
ERA Designed Equipment and Test Instrumentation
Insulation Development
Glove Cooling System
Glove Heating System
Deliverable and Prototype Gloves

Naturally, work often overlaps from one category to another or may pertain to more than the area under which it is reported. However, this should be minimal and any desirable cross referencing should be apparent.

GFE EQUIPMENT

The following were furnished (GFE) during the course of the program.

Part Number		Description
A7LB-103011-06/05	S/N340	Black Neoprene Space Gloves
S3L-106005-05	S/NDVT5001	Kevlar Space Glove
A7LB-203034-10	S/N353	Grey EVA Work Glove
O.E.S. Prototype	S/N001	New Design Kevlar Space Glove
A7L-103056-05/06	L/N510	Comfort Gloves

Part Number		Description
A7LB-109029-02&-02	S/N1029 & S/N1037	Wrist Disconnects
		Kevlar Fabric
		Urethane Material
		Metallized Kapton
		Urethane Adhesives
		Estane Edgelock
		"Non-Metallic Materials Design Guidelines and Test Data Handbook"

The leak rates of the GFE gloves were ascertained when the gloves were received.

Description	Leak Rate	
Black Neoprene Gloves		
A7LB-103011-05	1.0	S.CC./Min.
A7LB-103011-06	4.5	S.CC./Min.
Kevlar Glove		
S3L-106005-05	53	S.CC./Min.

The leakage from the urethane bladder of the Kevlar glove was thoroughly investigated.

The prototype glove was completely disassembled to expose the internal urethane bladder. The unit was then immersed in water to check for excess leakage which was found at the conclusion of the prototype design verification test at NASA. Eight leaks were found; four of the leaks were located at the tip of the four fingers. These appeared to be caused by sharp fingernails. One leak which appeared to be a puncture hole was located on the back side

of the little finger as may have been caused by a sharp finger ring. Two additional leaks were located on the wrist which again may have been caused by hand insertion while wearing a finger ring. Finally, a small leak was located where the urethane contacts the rim of the metal swivel base; this was probably caused by the urethane rubbing against the metal.

It should be noted that a high amount of wear occurs at the finger tips, particularly if comfort gloves are not consistantly worn and if the subject's hand were larger than can be accomodated by the glove. This reason increases the probability of leaks in the finger-tips. For instance, it was found that the urethane on some of the finger tips had grown thin either by wear or by overstretching during pressurization; therefore, it is suggested that increased protection such as a second layer of urethane be added to these areas in future gloves.

It should be noted that the inside seam of the Kevlar fabric covering the pressure bladder has a strong possibility of causing leaks. Edgelock is used on the edges of the Kevlar seam which hardens the fabric considerably, causing a somewhat sharp edge on the sides of each finger. When the outer covering was removed, the permanent impression of these seams was clearly seen on the urethane due to the 4 psia air pressure pressing the urethane against the Kevlar restraint. Therefore, it is suggested that a suitable precaution be taken against this danger. A possible solution could be to use Edgelock on only half of the seam so that the edges of the seam remain soft, thus preventing any sharp edges from occuring. Another suggestion would be to install split tubing on the seam to cover the sharp edge.

Another noteworthy point is that the urethane bladder was found to stick slightly to the Kevlar fabric when the bladder was being removed from the prototype glove. The sticking might have been due to a heat sealing effect which occurred in the pressurized mode at high temperatures (260°F and possibly above), or to the fact that the urethane was pressed into the small ridges of the Kevlar fabric in the pressurized mode, or it might have been due to a combination of the two effects. The maximum shroud temperature recorded was 260°F on thermocouple 11 on station D-D from the manned tests of July 2, 1975 at Houston. If it were due to a heat sealing effect and subsequent fabric pinching, it would be of value to keep this in mind as a possible source of glove failure during EVA missions.

The final glove, O.E.S. Prototype S/N001, bladder leaked excessively as received. An inspection of the final glove bladder (following removal of the outer Kevlar glove) indicated that it was fabricated from many small sections of flat sheet cut from a master pattern. Each of these pieces appeared to be adhesively bonded to its adjacent member with a simple edge overlap of approximately seven millimeters. Heat sealing, if utilized, was not obvious.

Competent, painstaking workmanship by the manufacturer was apparent, however there were many folds and creases along the seams. As many as 12 folds and creases per inch existed in several places. Many of the folds ran 4, 5, or 6.5 millimeters of the 7 millimeter seam width.

Assuming a perfect seal, it is unreasonable to assume that pressure, flexing, temperature cycling, etc. will not cause delamination of one or more of these folds in time. Secondly,

such transverse (to the seam) gas pathways caused by a fold may be pressure sensitive. In fact, several of these folds did open up with time.

Blow molded bladders would solve many of the observed and anticipated problems. Should this prove unfeasible, a secondary seal is strongly recommended. This might take the form of a second layer of urethane tape heat sealed and/or adhesive bonded to the inside surface while the bladder is pressurized in a high temperature ambient (perhaps 300°F). Ultrasonic or laser spotting along all seams might also be helpful. A very careful fit to the outer glove, as pressurized, is necessary to insure that no undue stretching of the membrane takes place. The wrist disconnect area of the urethane bladder was repleat with many major folds and delaminations of both a circumferential and radial nature. It is thus strongly recommended that a highly tensioned wrap of fine denier Kevlar filament be applied and sealed in addition to the current ring adhesive bonding.

It is also recommended that all gloves be heat soaked (at least 250°F) while pressurized at 9 psi or greater for a period of at least ten hours. They should then be leak tested and inspected prior to utilization by NASA or contractors such as ERA.

The excessive leakage of the GFE glove membranes caused considerable time loss in progressing with the main program. Telephone communication with NASA resolved the problem by NASA providing an approval to use a rubber membrane, as an expedient, for the ECHGS. Work on the GFE gloves was thereafter dropped.

However, NASA's earlier decision to employ urethane material for the pressure membrane appears to be a good one if additional

care is taken in the design and fabrication of future units. The higher strength of the urethane (rather than rubber) permits thinner material to be used and thereby improved tactilility should result. Moreover, a second bladder (two layers), possibly thinner than the first, may provide a highly desirable safety factor.

The GFE materials, particularly the Kevlar cloth, comfort gloves and Kapton material were used in the ECHGS. Kevlar thread was also used wherever sewing was required.

ERA DESIGNED EQUIPMENT AND TEST INSTRUMENTATION

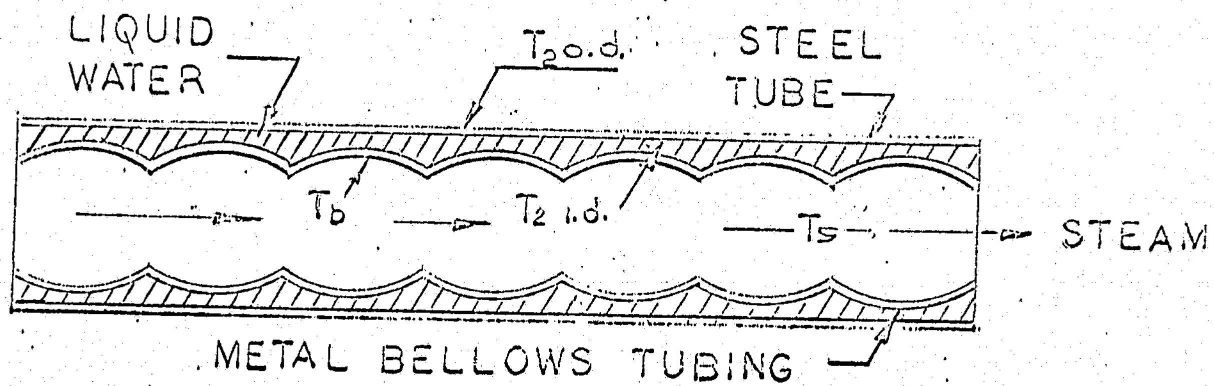
The specialized equipment which was engineered and fabricated for this program is described in this section.

Holding Bar

A variable temperature hand holding bar, $1\frac{1}{2}$ inches in diameter, was analyzed, designed and fabricated early in the program. This bar was designed to provide the $+200^{\circ}F$ and the $-200^{\circ}F$ test temperatures for the glove assembly. The bar consists of a 1/16 inch wall thickness, AISI type 304 stainless steel tube with an expansion bellows housed within the tube(Figure 1). An operational diagram of this system is shown in Figure 2. Steam was chosen for the heating media.

In the theoretical analysis of the system, estimates were made of: 1) the heating rate (Btu/min) required for the hot cycle; 2) the amount of water per minute needed to be evaporated by the boiler to supply this heating rate; and 3) the steam temperature, T_s,

STAINLESS STEEL TUBE INNER CONSTRUCTION



TERM DEFINITIONS

T_{2od} Temperature of the outer diameter of the stainless steel tube.

T_{2id} Temperature of the inner diameter of the stainless steel tube.

T_b - Temperature of the metal expansion bellows.

T_s Temperature of the steam.

STAINLESS STEEL TUBE HEATING SYSTEM

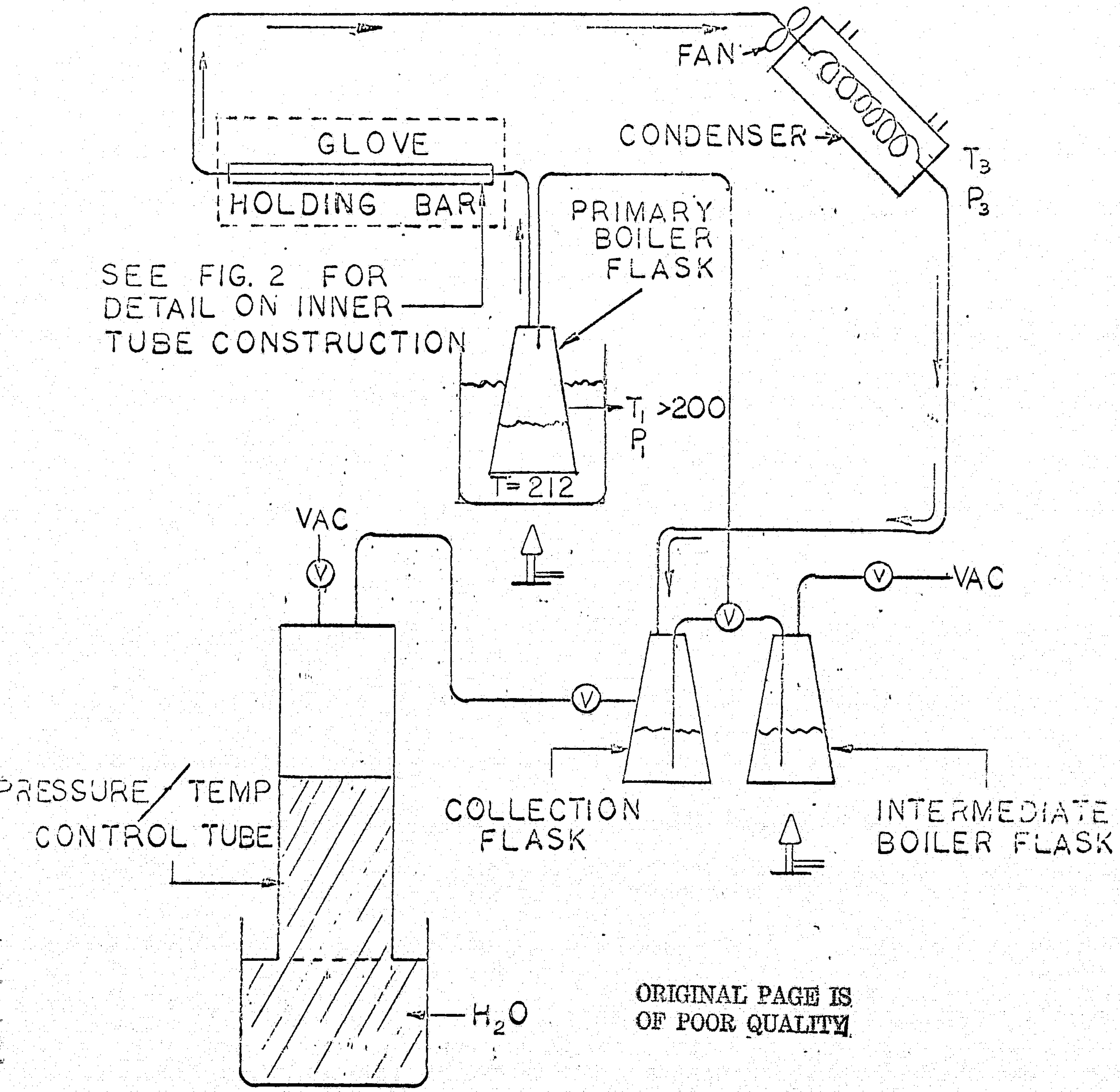


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Figure 2

required in the bellows tubing to provide +200°F at the surface of the holding bar.

The heating rate was established at approximately 212 Btu/hr. This was calculated by estimating the total heat losses that would occur at the holding bar. Specifically, the sum of the cooling rates that could be expected from the gloves (200 Btu/hr), and from the uninsulated areas of the steel bar (11.5 Btu/hr). Heat losses in the lines leading to the holding bar were considered negligible due to good insulation. The amount of boiler water required to supply this steam heating rate would be 98.9 mls water per hour, or 1.6 mls water per minute. The steam temperature, T_s, required in the metal bellows tubing to heat the surface of the holding bar was estimated to be 207°F.

The design for the heating system was determined by performing a test run with the heating system set up as shown in Figure 2. Problems with water condensing in the holding bar, and with the intermediate boiler flask aroase. These were eliminated by: 1) locating the holding bar above the boiler flask and the condenser so that any water condensing in the bar would run down into either the boiler or the condenser; and 2) eliminating the intermediate boiler. A functional diagram of the improved heating system is shown in Figure 3. The unit was fabricated in accordance with this desgin.

Early considerations to obtain the -200°F included the use of Freon 14 in the holding bar with operation at a pressure slightly lower than ambient resulting in the -200°F temperature. The use of liquid nitrogen was also considered early in the program

HEATING SYSTEM

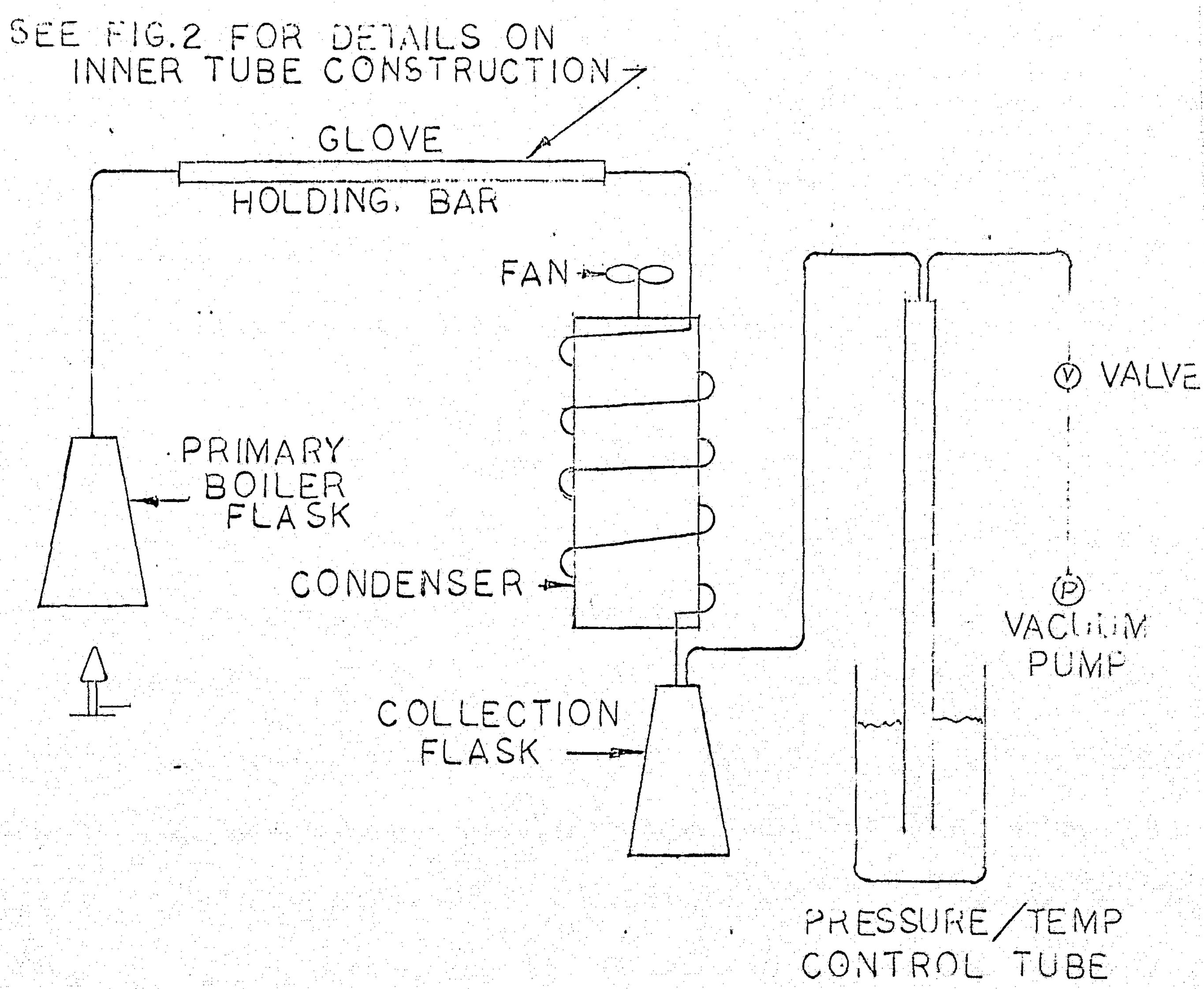

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Figure 3

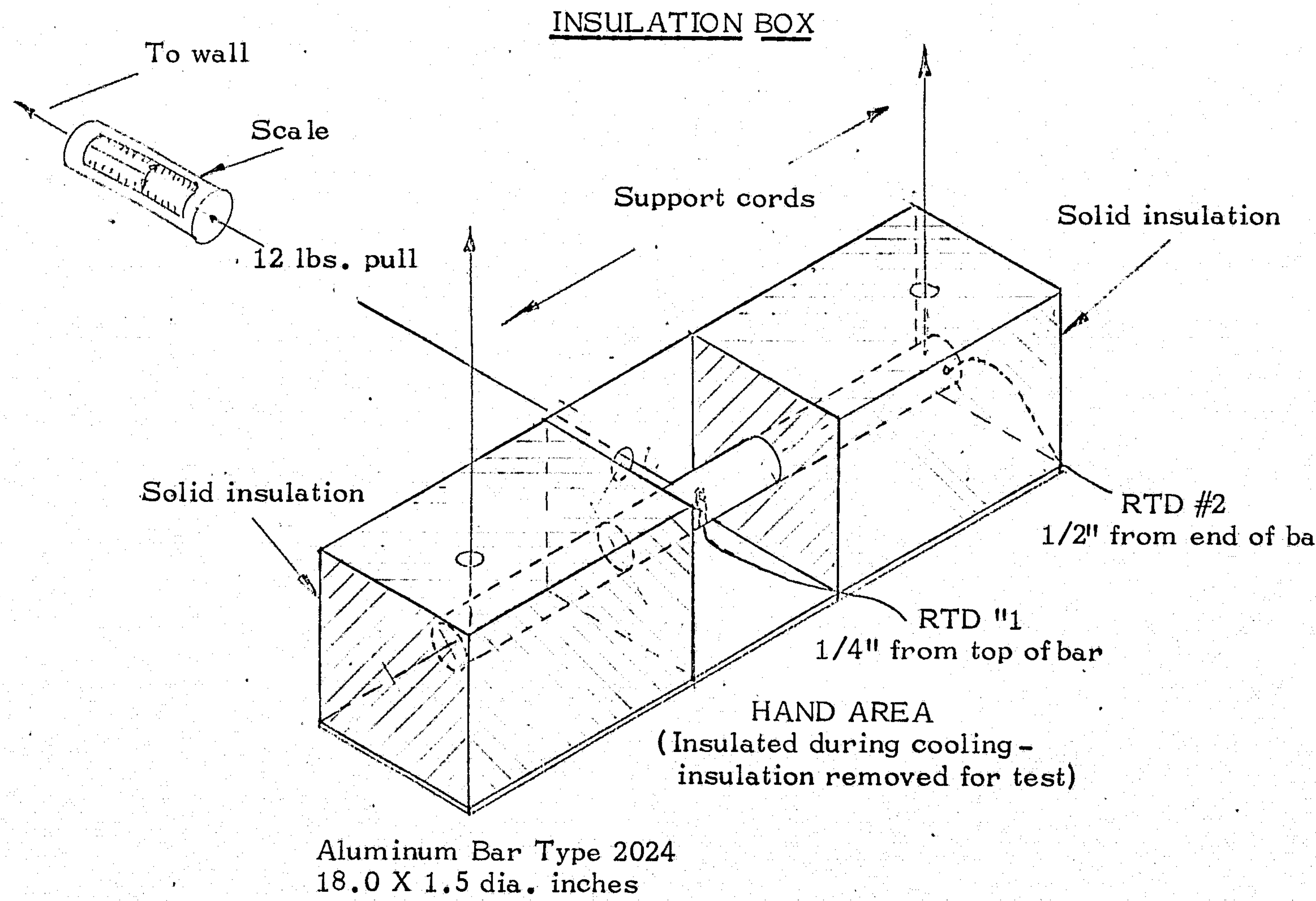
and this method was used for the cold bar in the final tests. However it was found expedient to use a solid aluminum bar which was insulated on each end and cooled, prior to test, with liquid nitrogen, Figure 4. Simple calculations showed that the heat sink capability of an 18 inch bar would permit a five minute hand test with approximately a $10^{\circ}F$ change in temperature. This simplified testing and eliminated a more costly development of a fully temperature controlled bar.

Vacuum System

The vacuum system was fitted with a glove box which was designed to place the glove in the vacuum environment with the arm in an atmospheric environment. As originally suggested in the proposal, a seal would be necessary at the arm to permit the glove to operate at 4 psi with an external vacuum and the test subject to be at 14.7 psi. This had two major drawbacks. A seal on the arm would be severely constricting to blood flow and thus adversely affect the test results. Further, if a failure of the glove occurred the decompression of the hand would be injurious to the test subject. Accordingly the glove box was used for outgassing test parts and conducting unmanned tests but it was not used for manned tests.

The main vacuum system produces a vacuum of 3 microns. A diffusion pump in series with the roughing pump lowers the pressure to less than 1 micron. A liquid nitrogen cold trap was added to facilitate the condensing of condensibles from the glove box or external load to improve the system efficiency. A second vacuum pumping system was plumbed to the glove box for added capacity.

FULL HAND PROTOYPE GLOVE - COLD BAR TEST



1. Aluminum bar imbedded in insulation except for hand area. Hand area insulated until just before test was started.

2. RTD's on fingers and thumb located between palm and proximal pads at proximal flexural areas.

Figure 4

Cold Block Assembly

The test apparatus used to attain temperatures of $-200^{\circ}F$ for patch testing is shown in Figure 5. Initially, a refrigerated copper plate was to be used with liquid nitrogen as the refrigerant. The copper plate was cast in polyurethane insulation. Temperatures of only $-150^{\circ}F$ were attained with this system. A similar idea was tried using a rectangular brass valve (1 inch by 2.5 inches). It was enclosed in polyurethane insulation with one side exposed to the ambient air. The test finger was to be placed on this surface during the test. This arrangement attained temperatures of approximately $-145^{\circ}F$. Heat flux from the air to the exposed surface was too great. Next, an arrangement using an aluminum block standing in a liquid nitrogen bath was constructed. This successfully produced temperatures of $-200^{\circ}F$ and below. Finally, an optimization of this arrangement brought about the final test apparatus shown in Figure 5.

Hot Block Assembly

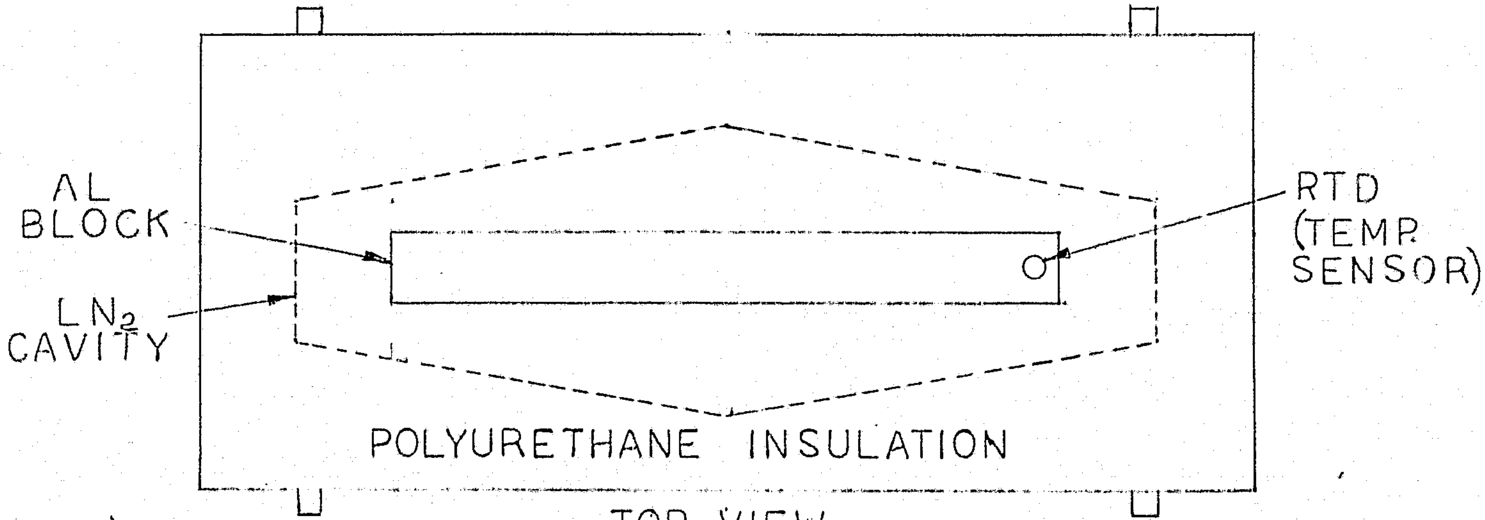
An electronically tested hot block assembly similar in size to the cold block but capable of being heated to $+200^{\circ}F$ or hotter was also fabricated.

Hot and Cold Block

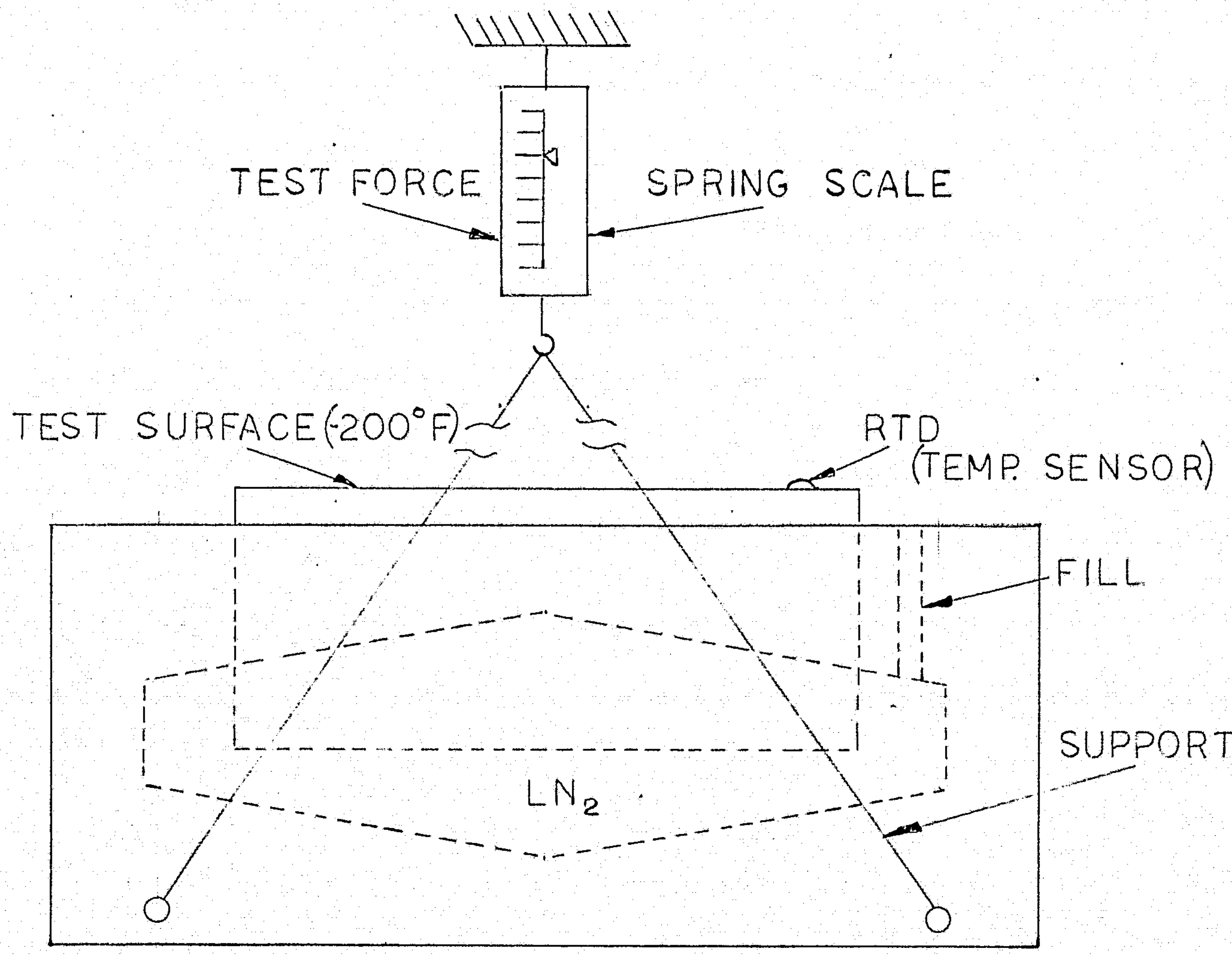
Testing System

Test fixtures were developed for un-manned insulation tests and to provide accrual indications of heat energy. An overall block diagram is shown in Figure 6. Either a heat sink cooled to $-200^{\circ}F$ (Figure 7) or a heat source heated to $+200^{\circ}F$ (Figure 8) was placed on the scale. Composite insulations to be tested were placed within the insulation carrier shown in Figure 9. The folded carrier was then inserted within the carrier fixture, Figure 10.

HEATING SYSTEM TEST FIXTURE



TOP VIEW



SIDE VIEW

Figure 5

COMPOSITE MATERIAL INSULATION TESTING

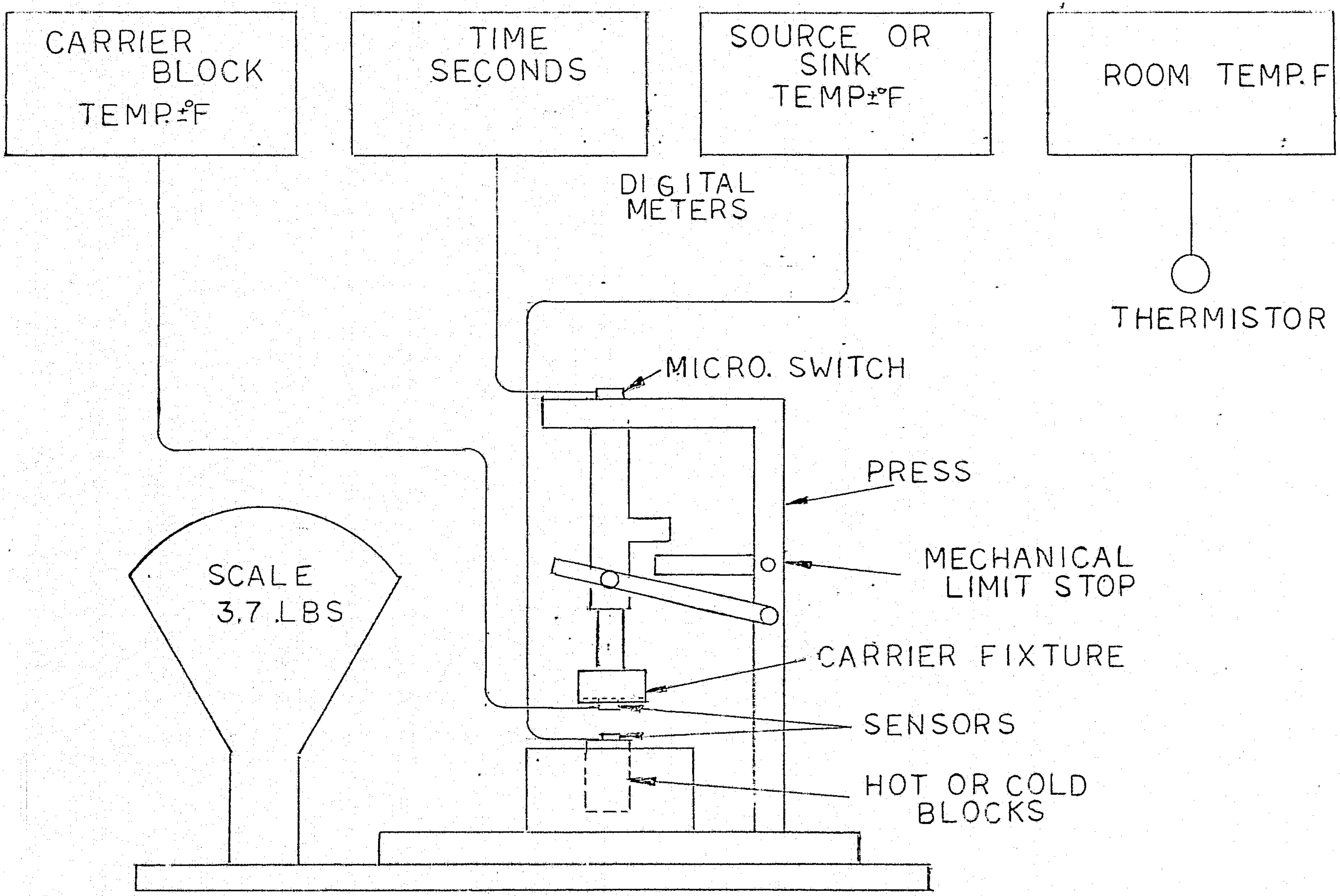
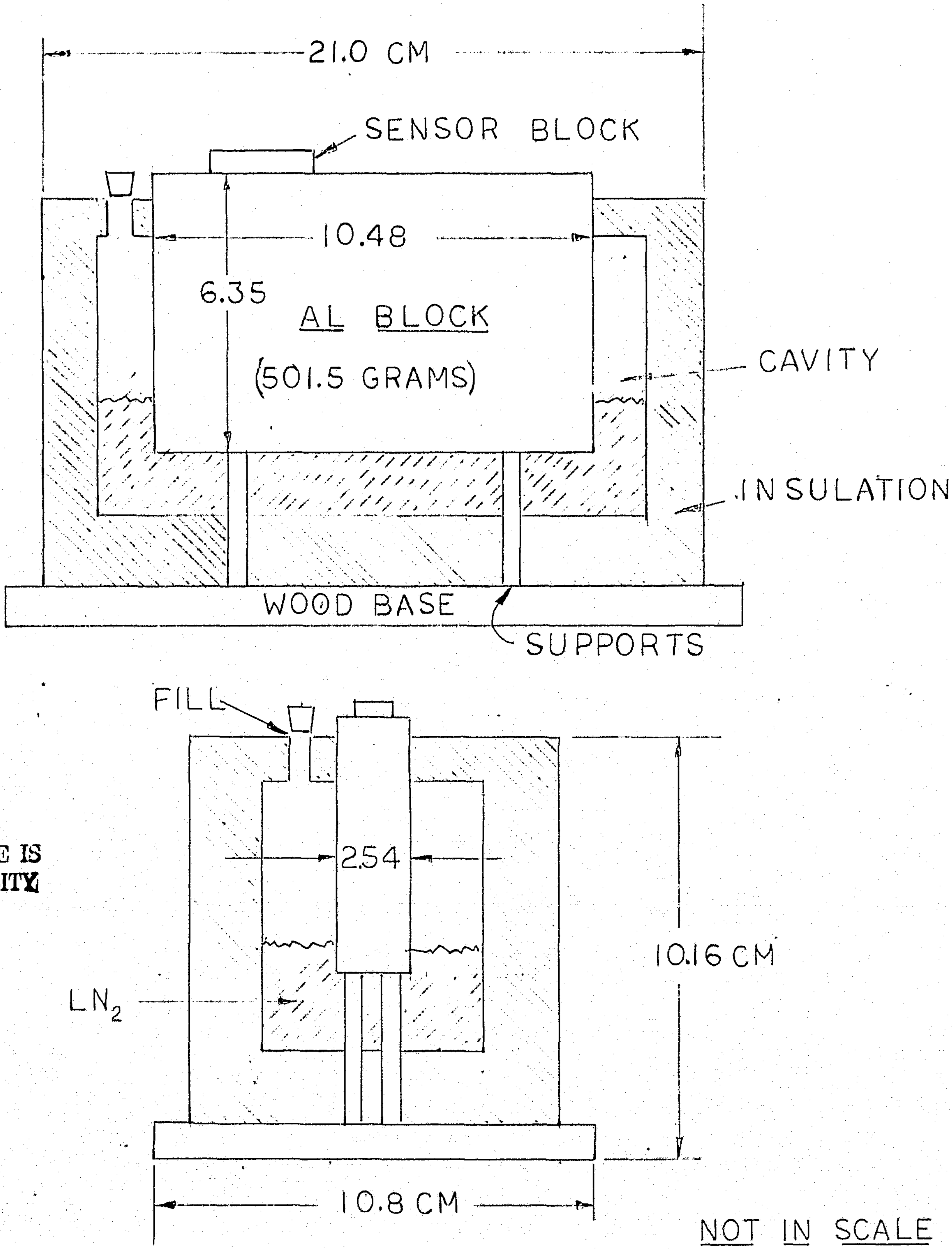
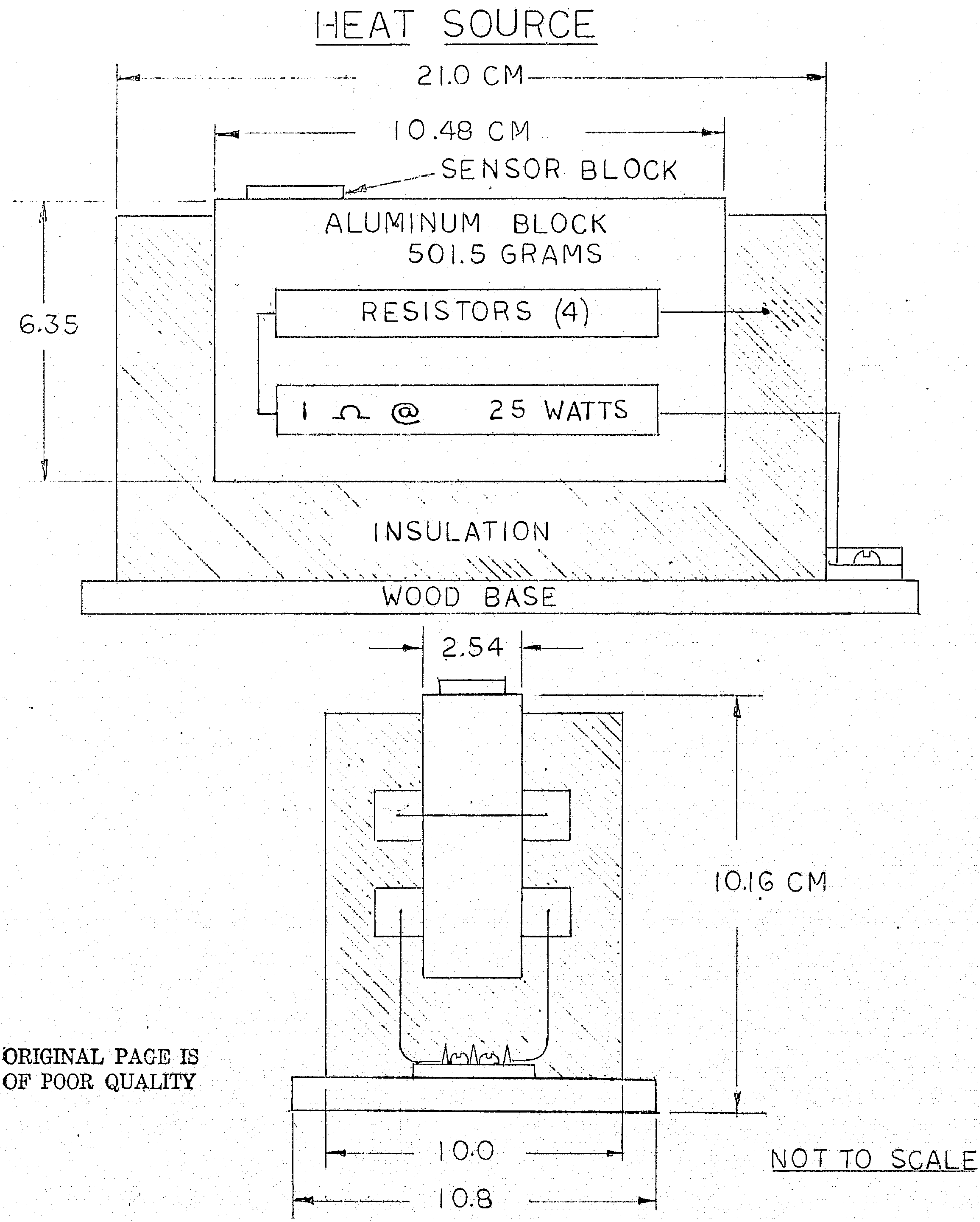


Figure 6

HEAT SINK



HEAT SINK, LN_2, TF-1 Figure 7



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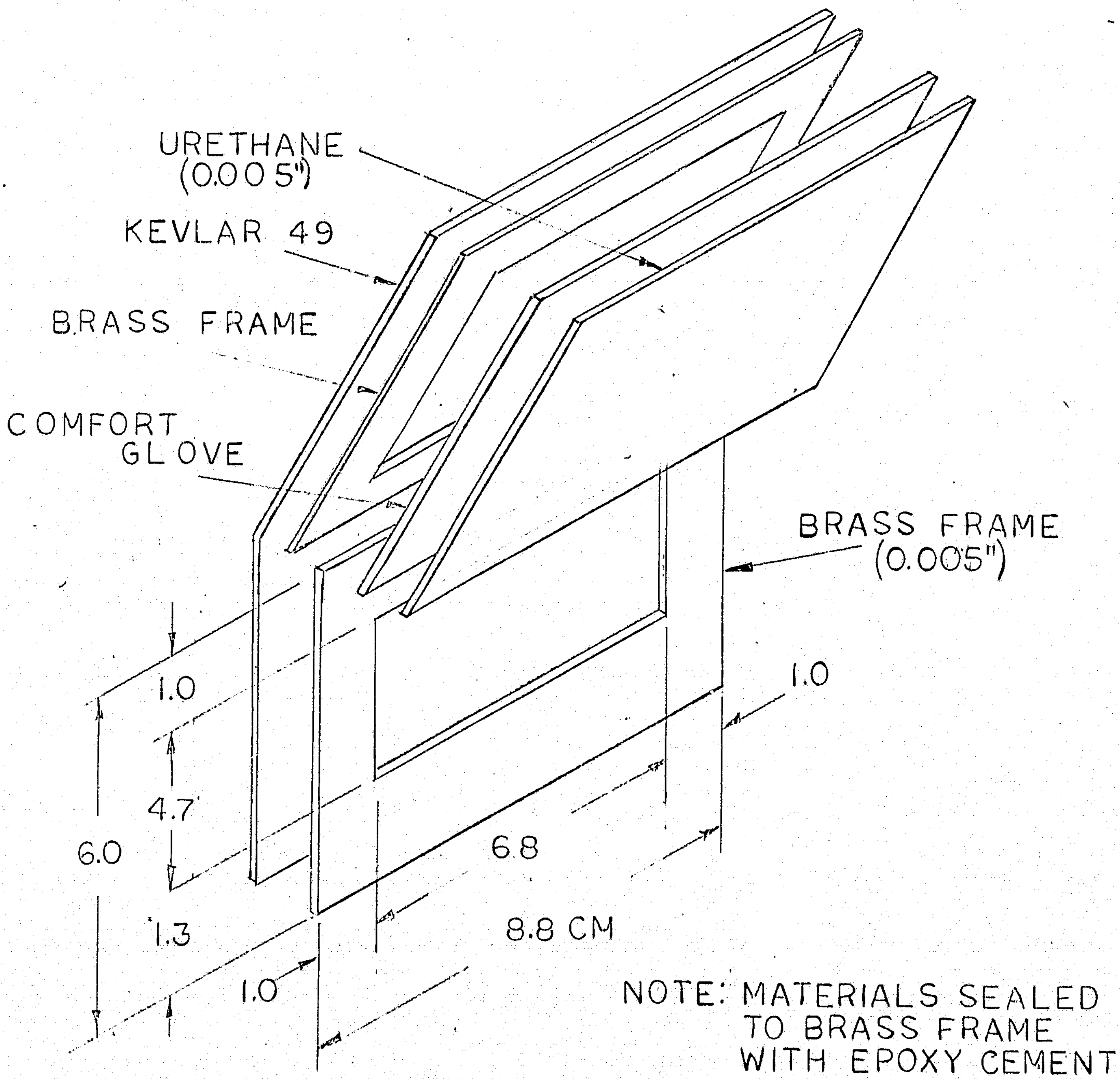
HEAT SOURCE RESISTIVE Figure 8

INSULATION CARRIER



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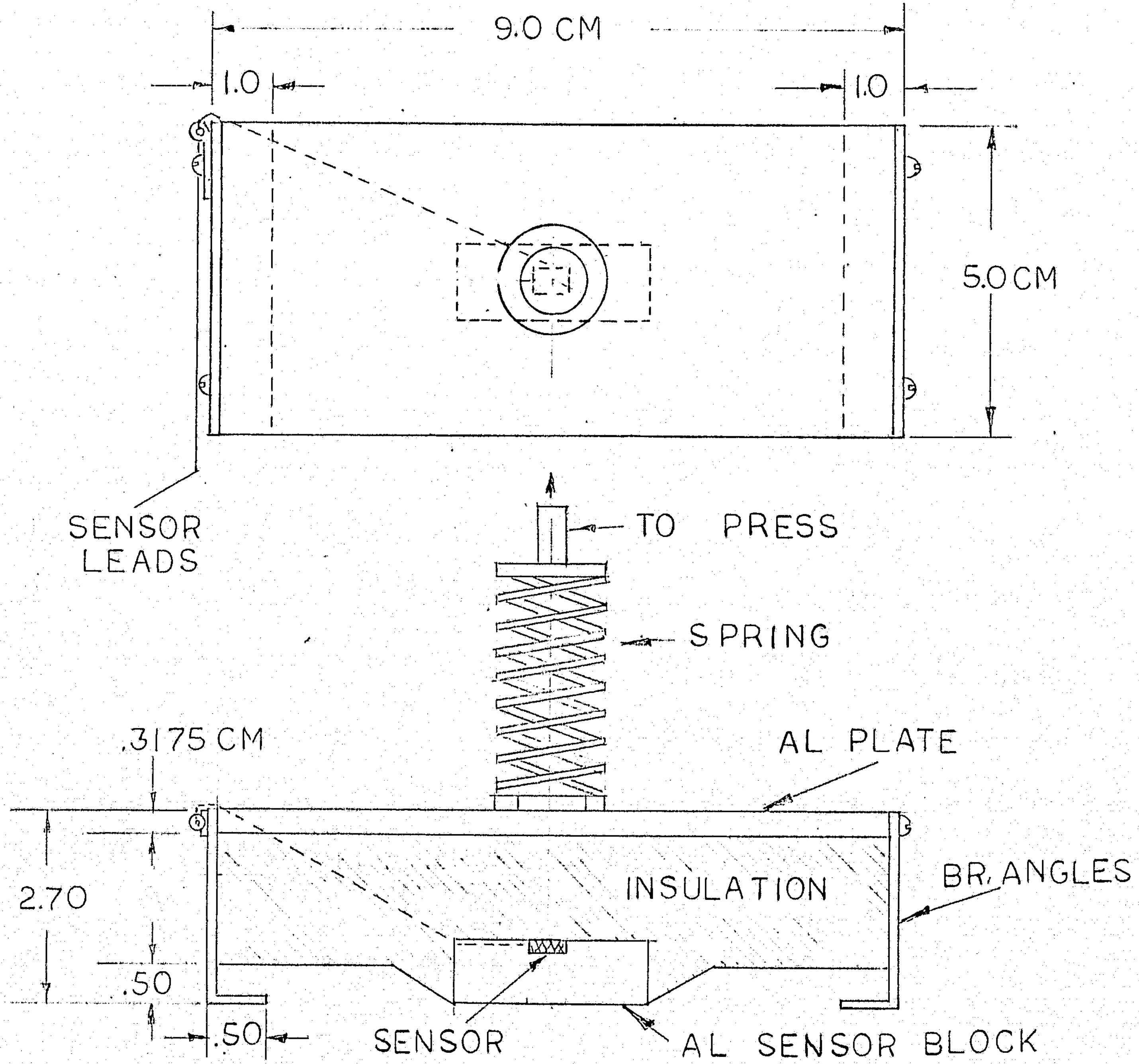
INSULATION CARRIER, PASSIVE.

Figure 9

CARRIER FIXTURE



NOT IN SCALE

At the start of a test the carrier and block temperatures were monitored and adjusted as necessary. In the case of a cold block, additional liquid nitrogen was added until the block stabilized at -200 to -210^{o}F. Also, in this case, the sensor block heater (Figures 11 &12) was held against the insulation until the carrier sensor stabilized at +100 ^{o}F.

The press was then activated to the preset mechanical stops, giving a force of 3.7 pounds (a pressure of 4.75 #/in^2) through the insulation and against the carriers 5 cm^2 sensor block.

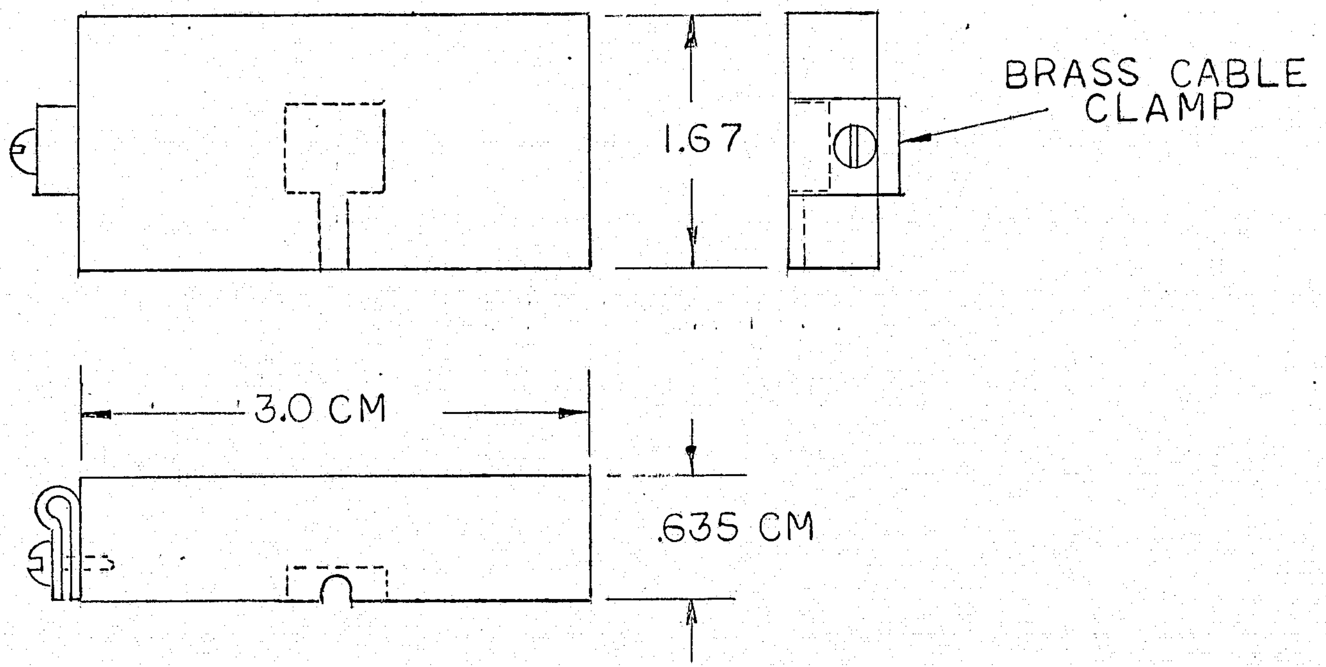
Temperature Measurements

The need of rapidly responding and accurate temperature measurements became obvious during preliminary passive insulation tests. In addition ice formations on certain manned test fingers were observed at a time when the finger temperature thermistors were still above 32^{o}F (but dropping rapidly).

A number of Rosemount Model 118 ABG miniature platinum resistance surface temperature sensors (RTD's) and Digitic 5746A Platinum Resistance Thermometers were acquired and calibrated. Two of the Rosemount 118 ABG's (serial U121 and serial U125) were calibrated by Rosemount (IPTS-68), as was a General Radio Decade Box which was utilized in calibration of all sensors. The 118 ABG sensor has a time constant less than 300 millisenconds and a temperature range of -260 to +260^{o}C. These sensors were used for all temperature measurements after acquisition.

SENSOR BLOCK

ALUMINUM BLOCK: 8.69 GRAMS
SENSORS, 0.4 X 0.4 X 0.14 CM



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SENSOR BLOCK, RTD

Figure 11

INSULATION/BLOCK HEATER, HAND HELD

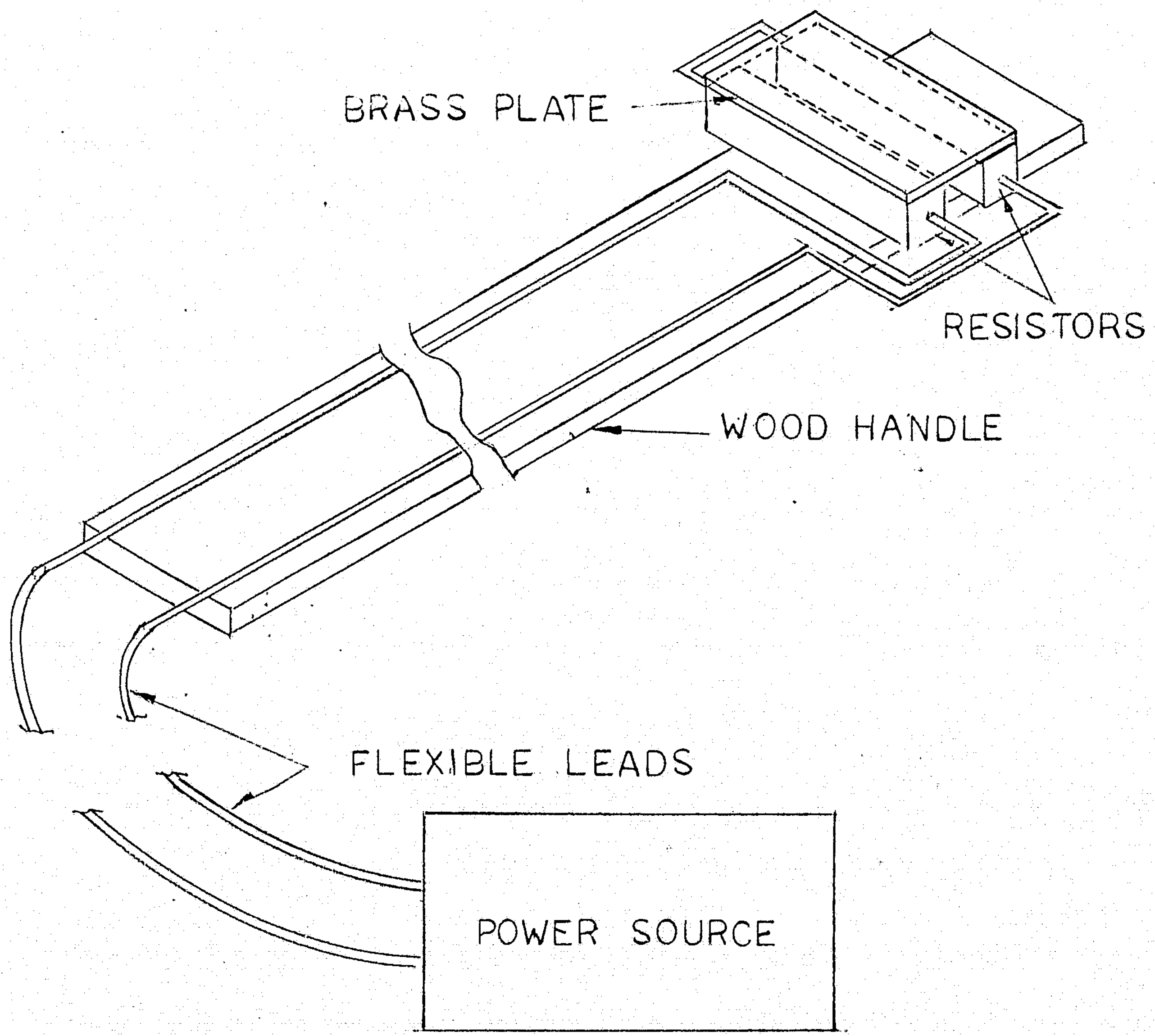


Figure 12

INSULATION DEVELOPMENT

The insulation characteristics of the GFE gloves was examined to provide initial information on the required heating and cooling rates.

A lengthy series of designs were made and tested to provide a minimum thickness insulation for the ECHGS.

A summary of bot types of tests follows:

GFE Glove Insulation Tests

Tests were conducted in order to determine the passive insulation properties of the prototype glove (GFE). That is, tests were conducted to determine the insulation characteristics of the prototype with the cooling system inactive, and with no heating system installed. The purpose of the tests was to provide data which would be useful in evaluating the requirements and loads that would be placed on the glove's heating system when contacting a cold object.

A diagram of the test set-up is shown in Figure 13, and the tests were conducted as follows: A simulated prototype glove-finger was fabricated, and its construction was identical to that found in the prototype glove as shown in Figure 14. The glove-finger was worn on the left-hand index finger of the test subject throughout all tests. A very small platinum thermistor was placed on the ventral surface near the end of the finger, just above the joint. It was found that 91°F was the approximate equilibrium skin-temperature of the finger when enclosed in the glove. Therefore, this temperature was chosen as the start and end point for the tests. When the skin temperature was 91°F, the finger was

INSULATION TEST SET-UP

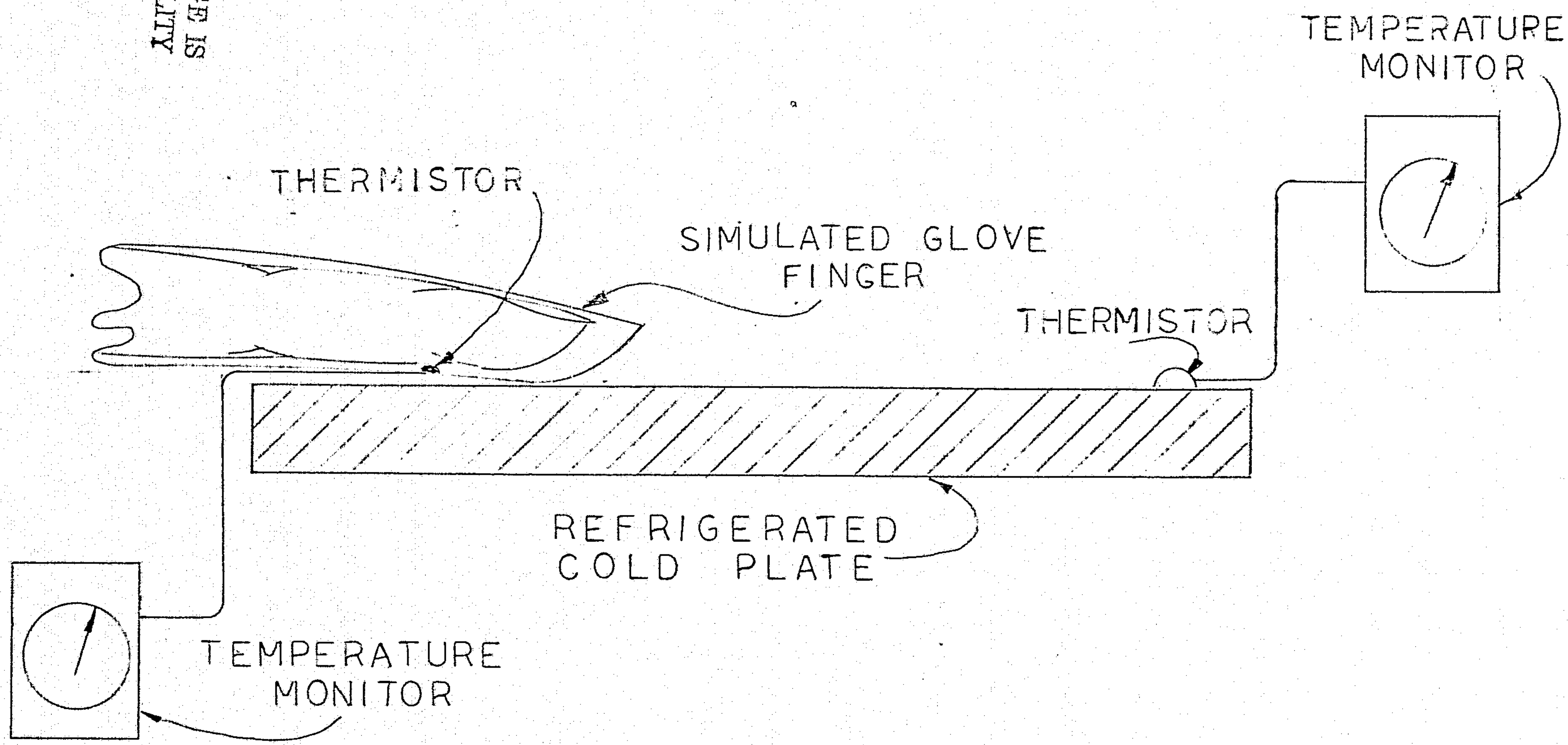
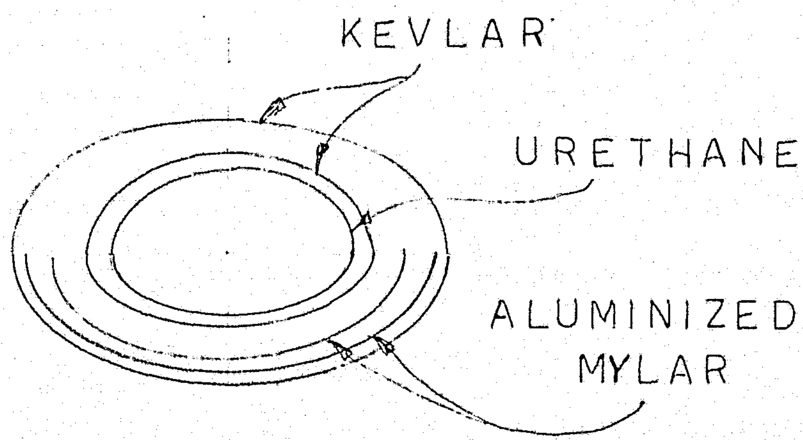


Figure 13

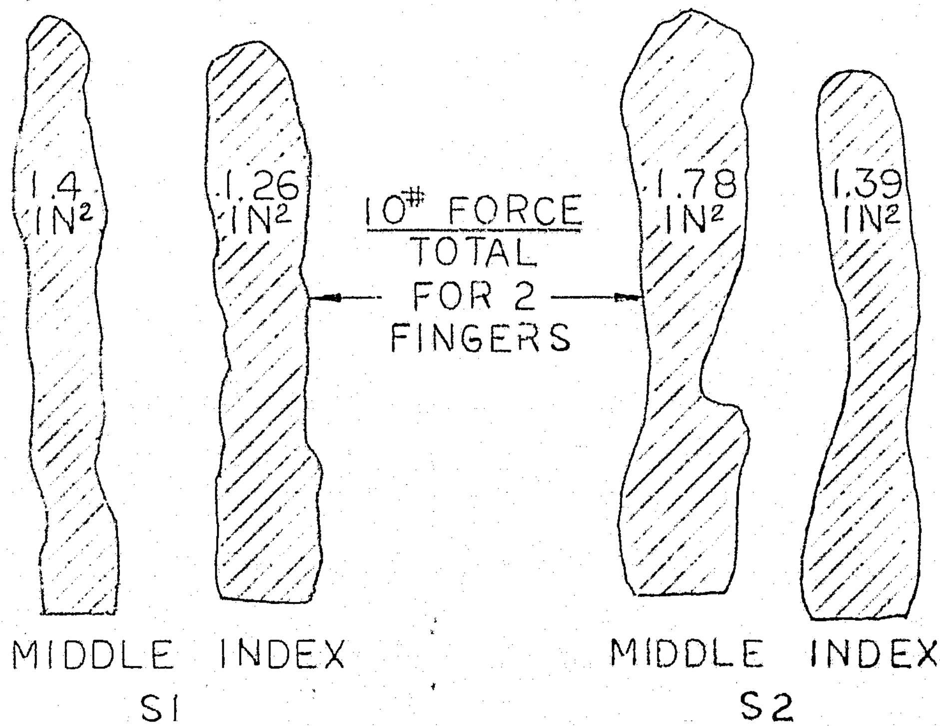
SIMULATED CONSTRUCTION GLOVE FINGER



placed on the cold source, and a record of time and skin-temperature was kept. Several different cold sources were used, in order to gain different cooling temperatures. The first was a refrigerated copper plate ($-6^{o}F$). The second was an aluminum plate precooled in a deep freezer ($-56^{o}F$) prior to start of test, $-22^{o}F$ at end). The obvious problem with this source was that the cooling temperature did not remain constant, but provided an intermediate curve in a family of tests. The third source used was dry ice ($-116^{o}F$). Tests using each source were done twice, one using the NASA comfort glove over the subject's finger (NASA part no. A7L-103056-06, L/N510), and the other using no comfort glove. Results of these tests are shown in Figure 15. An extremely noticeable increase in insulation was obtained with the comfort glove. For instance, using the comfort glove and the dry ice cold source, it took 2.3 times longer for the skin-temperature to reach $50^{o}F$ (the subject's finger became somewhat painful at this temperature, and will be taken as an arbitrary pain threshold), and 2.6 times longer to reach $31^{o}F$, than when using no comfort glove.

Also, two tests were made using the EVA work glove (NASA part no. A7LB-203034-10, S/N 353) in order to compare the prototype's passive insulation characteristics to those of the present EVA design. The second test was conducted, because the subject's finger was not properly on the dry ice during the first run. This appeared to make a difference in the outcome of the data as will be seen from the graphs. It is evident that the (GFE) work glove has better passive insulation properties than the prototype (GFE) glove. It will be noticed, however,

FINGER CONTACT AREA TRACINGS



MEAN PRESSURES, 10# TOTAL FORCE

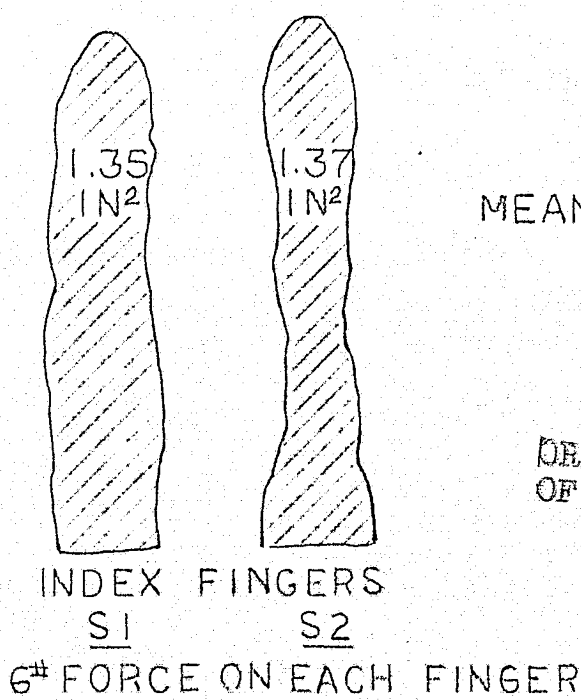
S1 3.74 P.S.I.

S2 3.15 P.S.I.

MEAN PRESSURES, 6# FORCE

S1 4.44 P.S.I

S2 4.38 P.S.I.



FACSIMILE FINGER CARBON TRACINGS

Figure 15

that in spite of its better insulation characteristics, the work glove is still not capable of maintaining the skin-temperature above $50^{\circ}F$ for three minutes even at dry-ice temperatures.

Subject Contact Area and Pressure Tests

Thermal conductivity studies require close control of both insulation contact area and pressure. A considerable amount of time was expended to obtain contact area tracings for each test subject under each of several test conditions. While simple to do, the procedure was subject to individual judgments, invited excessive experimental error, and allowed only average, not maximum, pressure determinations to be established for each test run.

Two completely separate determinations of area and pressure were made. The first of these utilized carbon imprint tracings for two subjects under two load conditions. A fascimile tracing and summary of results are shown in Figure 15 for subject R.S. who had a mean finger pressure of 3.74 pounds per square in. This data assumes (based on many previous tests) that the middle and ring fingers carry 83 percent, or 10 pounds of the contract specified 12 pound bar load.

A second independent test (resulting in a plaster cast) utilized the $1\frac{1}{2}$ inch steel gripping bar which was supported in an appropriate test fixture. A thin sealed partially congealed bag of quick setting plaster of paris was interspersed between the gloved or bare hand and the bar. The bar was then pulled to provide an indication of 12 pounds on a spring balance-pully system and was

maintained until the plaster was rigid. Table 1 summarizes the area/pressure analysis, again for subject R.S. Here it may be seen that a maximum pressure of 4.75 pounds per square inch was obtained at the proximal pad of R.S.'s middle finger, left hand. An explanation of terminology is shown in Figure 16.

Insulation Test - Experiment 1

A brief series of tests were run to 1) evaluate procedures and fixtures, 2) establish requirements for ongoing work, 3) evaluate possible replacements for cooling system insulation overlays prior to heating tests, and 4) gain insight into anticipated physiological activation.

Appropriate testfingers were fabricated and slipped inside covering fingers made up of the materials to be tested. A Rosemount 118 ABG sensor was taped to the subject's (S) finger by its leads such that the sensor was proximal to S's medial pad, middle finger. S then slipped on a comfort glove (which held the sensor against the skin) and the appropriate test finger. Time was allowed for the finger sensor to reach 95°F.

Coincidentally an experimenter pre-cooled the test fixture to -200°F with liquid nitrogen. S then placed his middle finger on the aluminum test block and applied enough force to cause a predetermined pound load indication to appear on the scale.

PRINCIPAL COOLING/HEATING AREA OF HAND — 12 POUND BAR

ANATOMICAL SURFACES *	EST. CONTACT PRESSURE (lb/IN^2)	EST. SURFACE AREA (IN^2)	EST. % OF PRESSURE (%)	EST. EQUIV. FORCE (lbs)
PROXIMAL PAD RING FINGER	4.53	0.53	20	2.4
MEDIAL PAD RING FINGER	4.0	0.57	19	2.28
PROXIMAL PAD MIDDLE FINGER	4.75 +	0.53	21	2.52
MEDIAL PAD MIDDLE FINGER	3.34	0.79	22	2.64
MEDIAL PAD INDEX FINGER	1.42	0.59	7	0.84
REMAINDER SEE FIGURE	0.66	2.0	11	1.32
TOTALS		5.01	100	12.00

*REFER TO APPENDIX _____ FOR EXPLAINATION OF TERMINOLOGY.

+INTERIM ERA STANDARD

Table 1

REFERENCE TERMINOLOGY

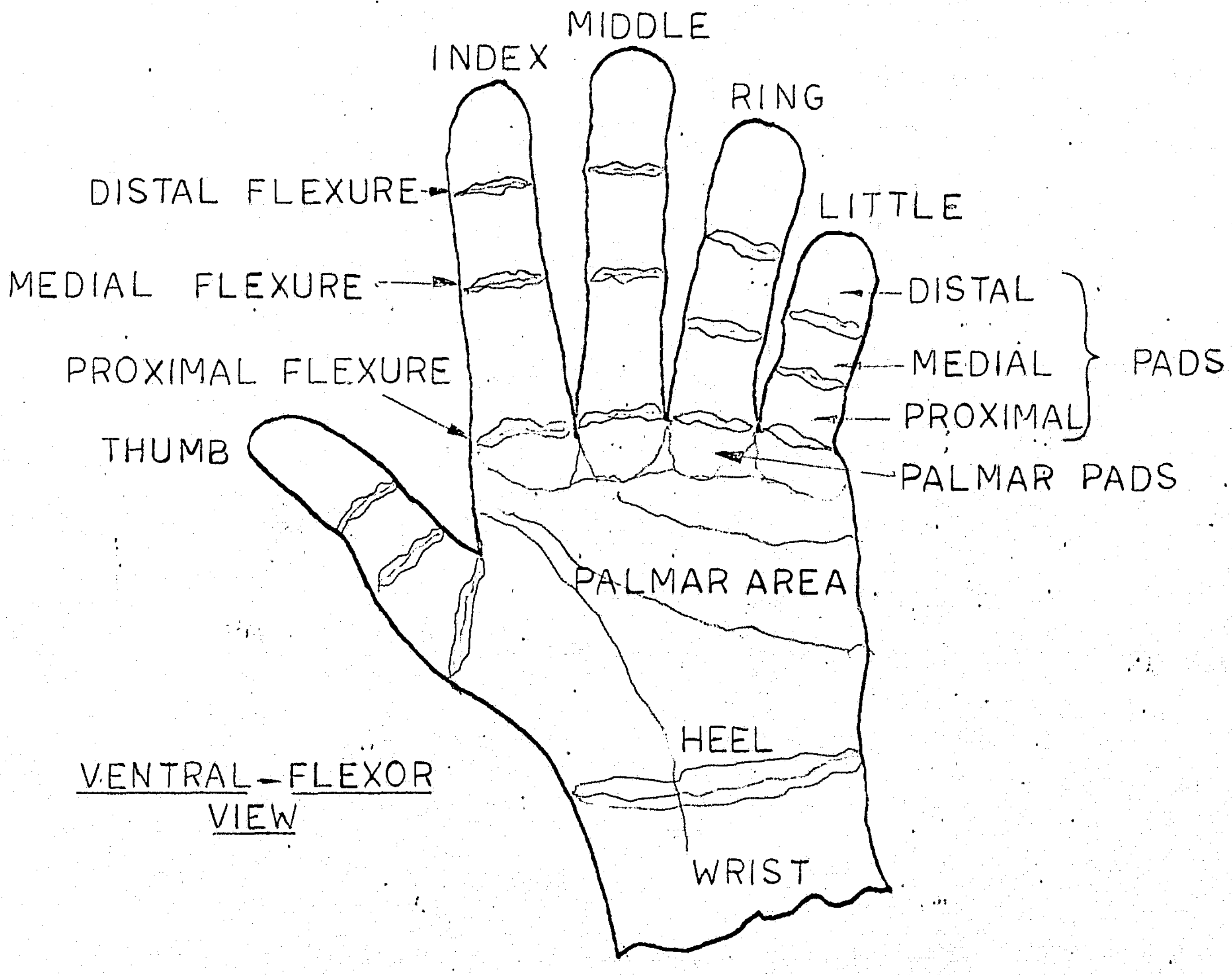


Figure 16

Finger temperatures were recorded every five seconds until a lower value of 50°F was indicated. The heat sink (cold block) temperature was recorded immediately before and after each run.

The following materials were utilized. They are listed in order from the surface of the hand.

	Test 1	Test 2	Test 3	Test 4	Test 5
1	Comfort Glove (CG)	CG	CG	CG	CG
2	Urethane (U)	U	U	U	U
3	Kevlar (KE)	KE	KE	KE	KE
4	Mylar (M)	M	Kapton(KA)	KA	KA*
5	Mylar (M)	M	Kapton(KA)	M	KA*
6	Kevlar (KE)	KE	KE	KE	KE
7	Kevlar (KE)				

*Non-aluminized

The experiment verified the need for more flexible and controllable methods for passive insulation testing. In addition a number of technical items and insights are inferred even though the data base is quite small. Reference will be made to Table 2, Experiment 1 Summary Data and Figure 17.

The majority of composite thermal resistance is provided by the Kevlar. This is readily seen by comparison of Test 1 and 2, Figure 17 wherein the only difference was one layer of Kevlar. Activation for S1 is clearly evident in Tests 1 and 2. S1's complete

EXPERIMENT 1 SUMMARY DATA

TEST	TRIAL	SUBJECT S1	SUBJECT S2	TIME (Sec.) to 50°F	INTER-TRIAL DIFF. (Sec.)	-SLOPE °F/sec. 90-50 F	NOTES*
1	1	X		40		1.12	
	2	X		60	+20	0.75	
	3		X	42		1.07	
	4a		X	34	-8	1.32	Comment 4
2	1	X		23		1.95	
	2	X		36	+13	1.25	
	3		X	23		1.95	
	4		X	22	-1	2.04	
3	1	X		37		1.22	
	2a	X		19	-18	2.37	Comments 4
	3		X	20		2.25	
	4		X	23	+3	1.96	
4	1	X		16		2.81	
	2	X		20	+4	2.25	
	3		X	31		1.45	
	4		X	24	-6	1.87	
5	1	X		17		2.65	
	2	X		17	0	2.65	
	3		X	21		2.14	
	4		X	18	-3	2.50	

Table 2

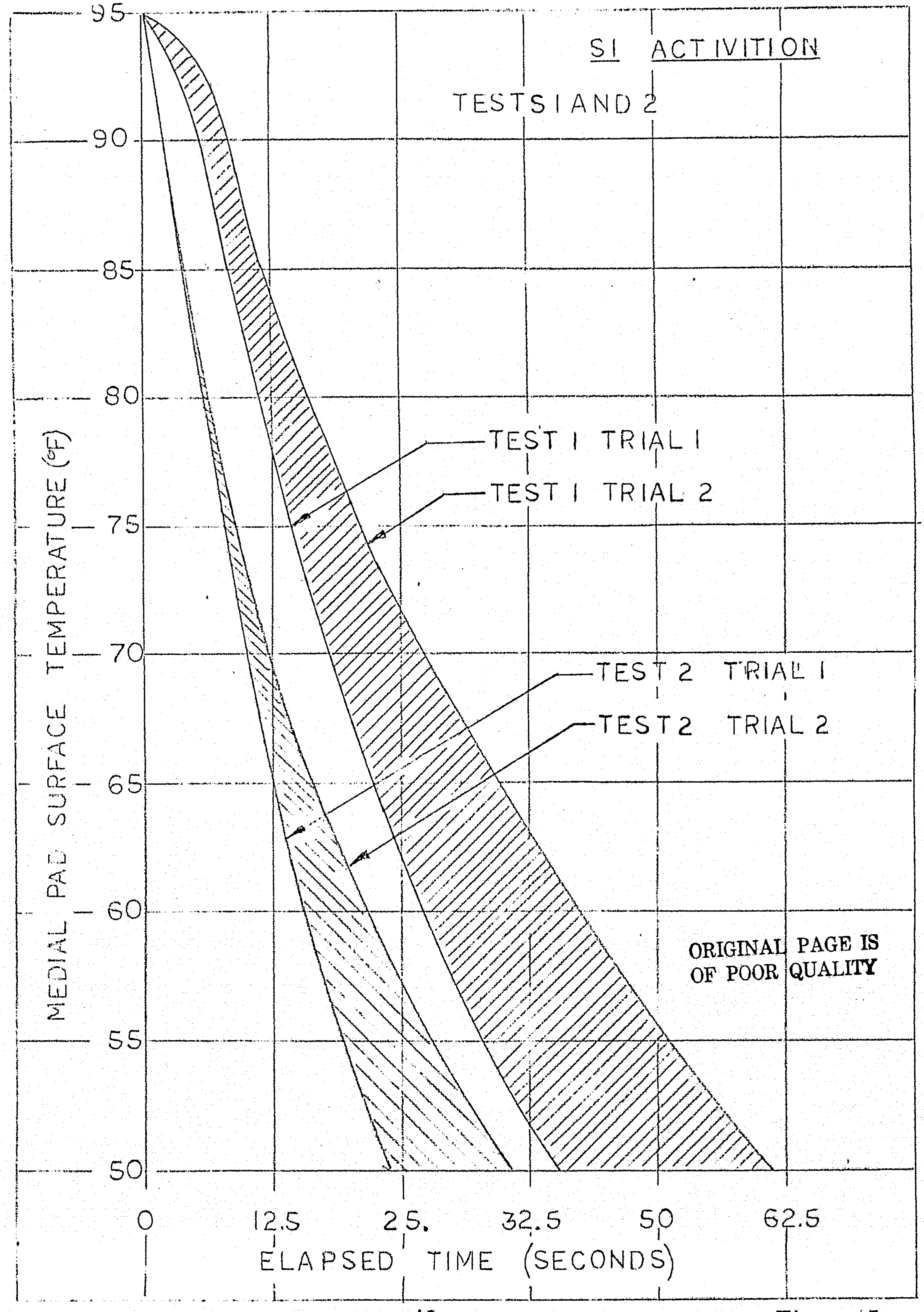

SI ACTIVITION
TESTS I AND 2
TEST I TRIAL I
TEST I TRIAL 2
TEST 2 TRIAL I
TEST 2 TRIAL 2
MEDIAL PAD SURFACE TEMPERATURE (°F)
95
90
85
80
75
70
65
60
55
50
0
12.5
25.
32.5
50
62.5
ELAPSED TIME (SECONDS)

Figure 17

data for these tests may be found plotted in Figure 17. The shaded areas between the trials is a rough measure of increased digit thermal capacity.

An experimental test series was conducted to test composite insulation systems. Refer to Figure 6,7,9,10 and 12 (Equipment and Instrumentation Section).

The Heat Sink (Figure 7) and the Carrier Fixture (Figure 10) were set up as shown in the Block Diagram (Figure 6). Material composites to be tested were then fabricated and inserted into the Insulation Carrier (Figure 9). This was in turn inserted into the Carrier Fixture and the press was set for the desired force, nominally 3.7 pounds (4.75 pounds per square inch). The Heat Sink (Figure 7) was then cooled to -200°F while the insulation and sensor block were heated to +100°F by use of the Block Heater (Figure 12). The press was activated and data such as temperature and force was recorded as a function of time, generally at 5 second intervals.

Two or more trials (data runs) were made for each composite insulation. The data was then averaged and normalized. Changes from initial conditions (delta's), slopes, and various energy relationships relating to glove design requirements were calculated.

A large number of practice runs were required using the carrier only (Kevlar, Comfort Glove, Urethane, and Kevlar layers). A best of six average was computed for the carrier block temperature change. These data are shown in Figure 18 relating

PASSIVE INSULATION CARRIER BLOCK TEMPERATURE VS. TIME

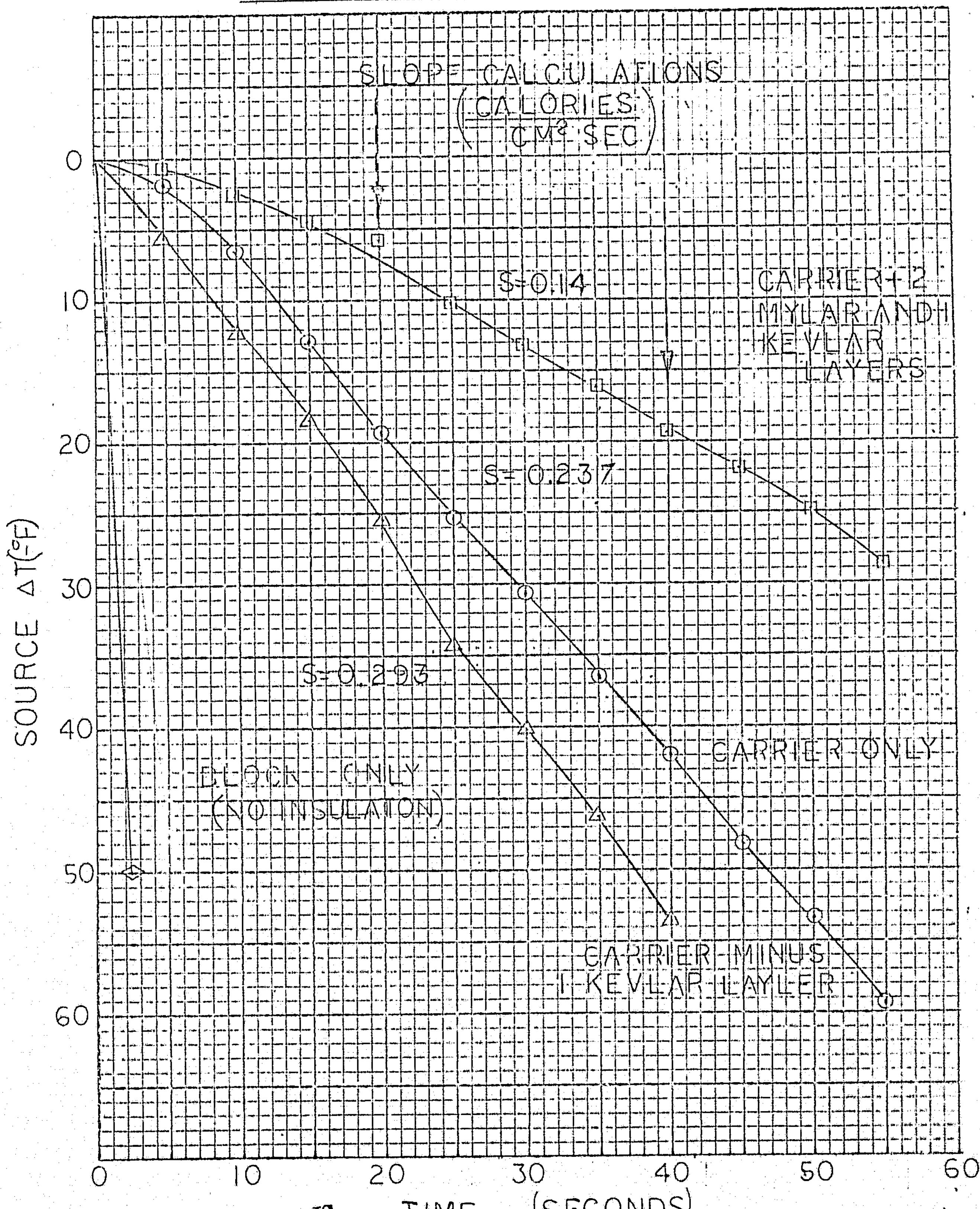


Figure 18

passive insulation carrier block temperature vs time. The slope of the carrier only curve (taken between the indicated 20 and 40 second arrows) is an indication of thermal energy (Q) flow through the carrier insulation as a result of the approximately 260 to 280°F temperature gradient across the insulation. Since the surface area (5 cm^2), mass (8.69 grams), and specific heat (.2145) of the sensor block were known, the magnitude of this energy flow was computed. For the carrier only this value was found to be 0.237 calories (mean) per square centimeter-second.

Also shown in Figure 18 are similarly derived curves for both the highest and lowest thermal conductivity composites tested to date. Of these 21 composites an inclusion of one Kevlar glove material layer tends to mask out each of the other material's contribution to overall conductivity. The "block only" curve (metal to metal contact) is presented to indicate that an adequate instrumentation system time constant was achieved. Other non-reported tests showed that the temperature indicator time constant was far longer than sensor and sensor block dispersion (h^2) constants. Thus the true reading was available as soon as it was displayed.

The top 3 and bottom 3 ranked insulation composites are shown in Figure 19. Referring to Figure 19, the (-) slopes shown in column 4 were determined between the 20 and 40 second intervals as previously discussed. Assuming a condition wherein no heat is supplied by the finger pad and also that the pad temperature remains constant at, say, 95°F, then the value of Q (thermal

RANK (OF 21)	MATERIALS IN ADDITION TO CARRIER	NOTES	-SLOPE $\left(\frac{CAL}{CM^2\ SEC}\right)$	+Q FOR $\Delta T = 0$ @180 SEC $\left(\frac{CAL}{CM^2\ 180}\right)$	+Q FOR $\Delta T = 0$ $\left(\frac{K\ CAL}{HAND\ HOUR}\right)$	+Q FOR $\Delta T = 0$ $\left(\frac{BTU}{HAND\ HOUR}\right)$
1	MMKe	2,3,	.14	25.20	16.25	65
2	Ka S Ka	1,4,5	.1648	29.67	19.14	76
3	Ka S Ka	1,4,5	.1903	34.25	22.09	88
REF.	0	6	.2376	42.77	27.59	110
19	M	3	.2288	41.20	26.56	106
20	Ka Ka	1	.2454	44.17	28.49	114
21	-Ke	2	.2933	52.78	34.05	136

NOTES:

1. Ka - Metalized Kapton
2. Ke - Kevlar
3. M - Metalized Mylar
4. S - Dacron Spacer
5. Gold toward sink
6. Insulation carrier, composed of 1 layer each of Ke, comfort glove, urethane, and Ke.

RELATIVE PASSIVE INSULATION RANKING

Figure 19

energy) shown in column 4 must be supplied by the heating system. Referring now to Figure 20, the generator G2 must supply the thermal energy indicated in column 4 of Figure 19, each second (and for each cm^2 of area) if the thermal resistors R2 and R3 were to be made up using only the materials indicated in column 2.

In a like manner column 5 indicates the required generator (G2) output for the specified 180 second contract test period. The actual (G2) thermal output requirement will be, of course, reduced by the allowable depletion of finger tissue thermal energy. Since physiological thermal outputs only can be determined following NASA specification of particular EVA mission profiles, the worst case energy requirements for (G2) are thus indicated in columns 6 and 7. Another series of passive insulation tests were run, and 5 selected sets of data and are summarized in Figure 21, Relative Passive Insulation Ranking. Also see Figure 19 and the discussion related to same.

Two additional columns of information are presented in Figure 21 (compared to Figure 19) for the various insulations. Column 5, Resistance, was the effective thermal resistance of the test patch alone, with the exception of the two values shown for the Insulation Carriers. In the case of the carriers, the resistance shown was the total test thermal resistance. In addition, the value shown for Carrier 2 included the effective value for the Nylon Vacuum bag.

EQUIVALENT CIRCUIT, THERMAL GLOVE SYSTEM

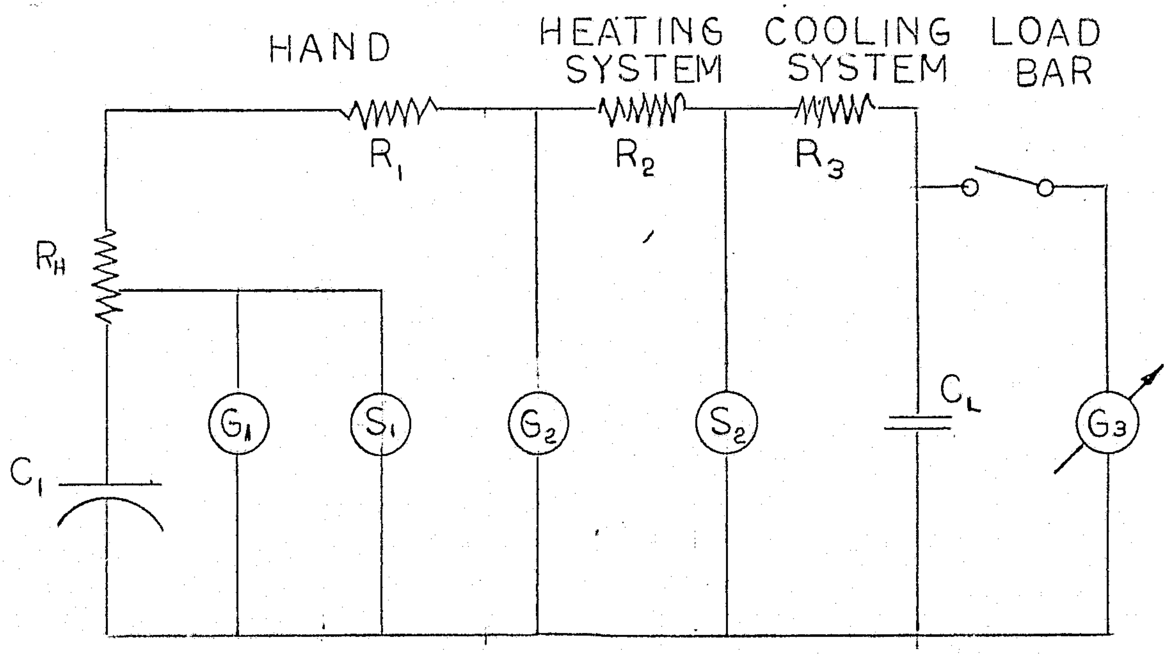


Figure 20

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PASSIVE INSULATION RANKING

RANK (OF 37)	MATERIALS IN ADDITION TO CARRIER	NOTES	-SLOPE (CAL / CM² SEC.)	RESISTANCE (SEC. CM² °F / CALORIES)	G2 REQ. FOR ΔT=50@180 SECS. (CALORIES / CM²)	+Q FOR ΔT=0 @180 SECS. (CALORIES / CM²·180)	+Q FOR ΔT=0 (K CALORIES / HAND·HOUR)	+Q FOR ΔT=0 (B T U / HAND·HOUR)
REF.	Carrier 1 TF-3	1	.2376	676.3	45.8	42.77	27.59	110
REF	Carrier 2 TF-10	2	.2506	639.5	49.9	45.1	29.1	115
1	2KE 2M Ke	2,3,4,5	.0660	1788	-7.0	11.89	7.67	30.4
2	2Ke Cu Ka	2,6,7	.0878	1186	- .3	15.8	10.2	40.5
3	Ka N.S. Ka Ke	2,5,8	.0926	1091	1.2	16.7	10.8	42.6
4	4 Ka 3 N.S.	2,9	.1144	724	7.9	20.6	13.3	52.9
5	2Ke 2M Ke	2,9	.1217	677	10.2	21.9	14.1	56.3

NOTES

1. Insulation Carrier, compo: of one layer each Ke, Comfort Glove, Urethane and Ke.
2. Insulation carrier, compc of one layer each of comfo. glove, Rubber, and Ke.
3. Ke - Kevlar 29
4. M - Metalized Mylar
5. 50 Micron Vacuum
6. Cu 1x65x44 copper strand
7. Ka - Metalized Kapton
8. N.S. - Nylon Spacer
9. Evacuated Nylon Bag

Figure 21

Column 6 lists the calories per centimeter required from the heating system over the 180 second test period, assuming an allowable finger temperature drop of 50°F and a total finger thermal output of 37.8 calories (0.15 BTU) per centimeter. The Carrier 2 insulation was included in these calculations as was the approximate 10.4 calories per square centimeter contribution made by the sensor block.

A test block temperature vs time comparison of the Rank 1 and 2 patches is shown in Figure 22, Passive Insulation Test Comparison. The data is presented in this form to allow correlation with the tests of other materials and non-vacuum passive test techniques.

One possible source of confusion is that the curves on Figure 22 intercept the Delta temperature line (50°F) at a value less than 180 seconds, while Figure 21 Data indicates a small excess of energy at 180 seconds. Only the test block energy (10.4 calories per square centimeter over 180 seconds) is available during the tests in the data plotted in Figure 22, while a value of approximately 37.8 calories will be available from a gloved finger.

The final glove insulation pack was designed from the results of the component tests plus the necessity of integrating the evaporative cooling system (wicking and water feed tubing). Further details of the insulation pack are provided under the Description section of the ECHGS.

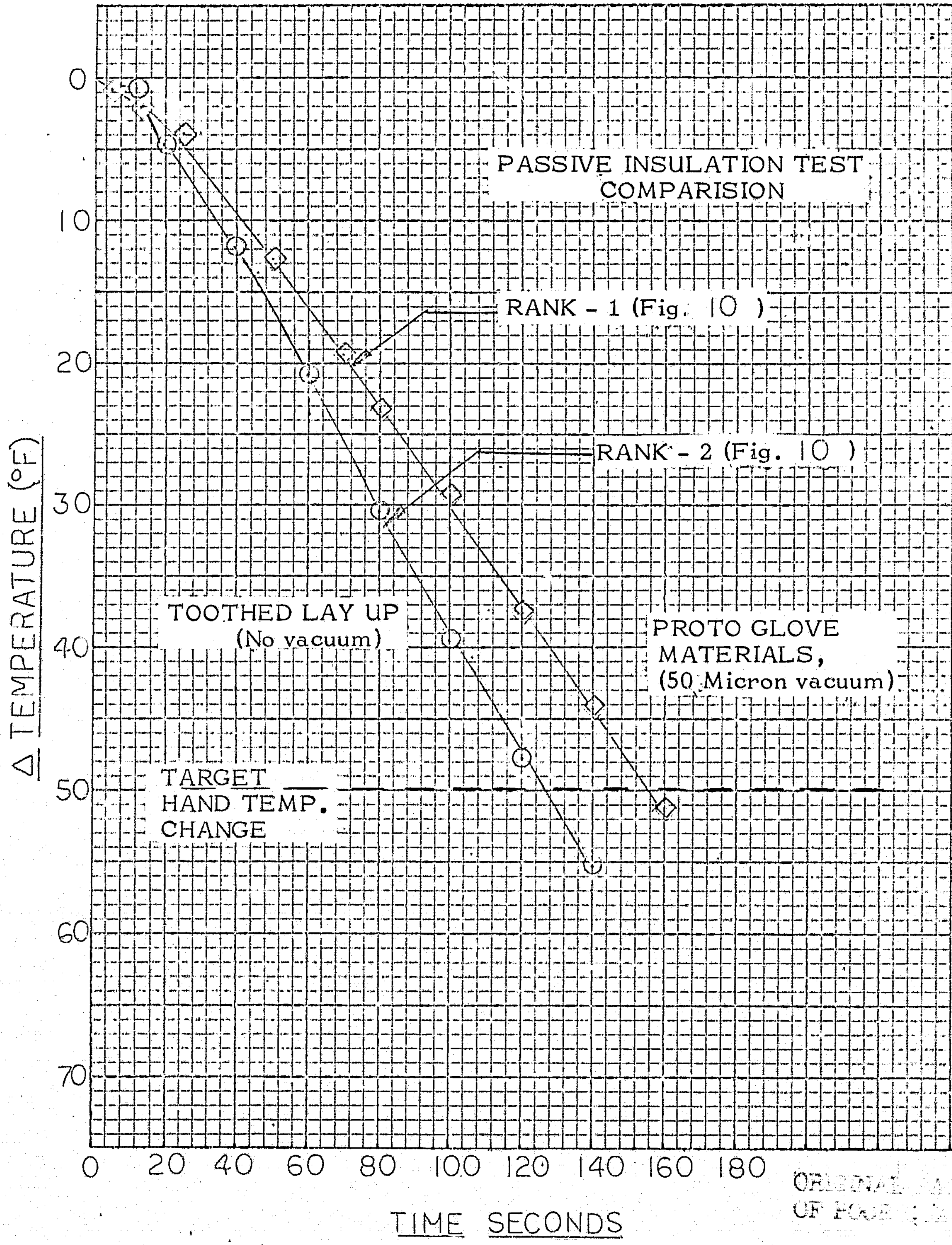

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Figure 22

GLOVE COOLING SYSTEM

As proposed in the ERA Proposals, water evaporation was a main contender to achieve the necessary results. During the Proposal, use of the Evaporative Cooling Garment System (ECGS) principle, wherein the water to be evaporated is contained in gas tight envelopes and the evaporation is controlled by valving the steam pressure at controlled rates, was proposed, (note: The ECGS was developed for NASA by Mr. Bitterly while he was with Douglas Aircraft - please see the Proposal). Subsequent negotiations with NASA resulted in the desirability of direct evaporation to space. Accordingly, the following program work was done, essentially sequentially as presented, to develop this system. An analysis of the hand gripping area showed that any cooling segment must withstand about 2-3 psi, while still maintaining spaces between the layers of the insulation pack to allow sufficient evaporation and gas (steam) flow for cooling.

The general construction of an early cooling segment is shown in Figure 23. It consists of a wicking layer made of 0.069 inch cotton on the bottom, a 0.0133 inch Kevlar layer on the top, and a spacing material in between to maintain the evaporation space between the wicking layer and Kevlar. A variety of spacing materials were examined and tested in experimental cooling segments (2 x 4½ in.). These included the following:

OPEN EVAPORATION COOLING SEGMENT CONSTRUCTION

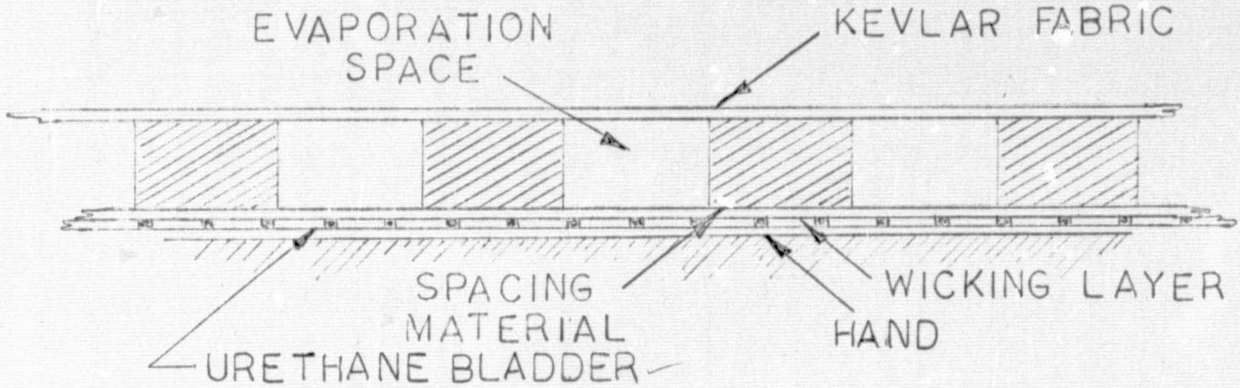

Figure 23

OPEN EVAPORATION COOLING SEGMENT CONSTRUCTION

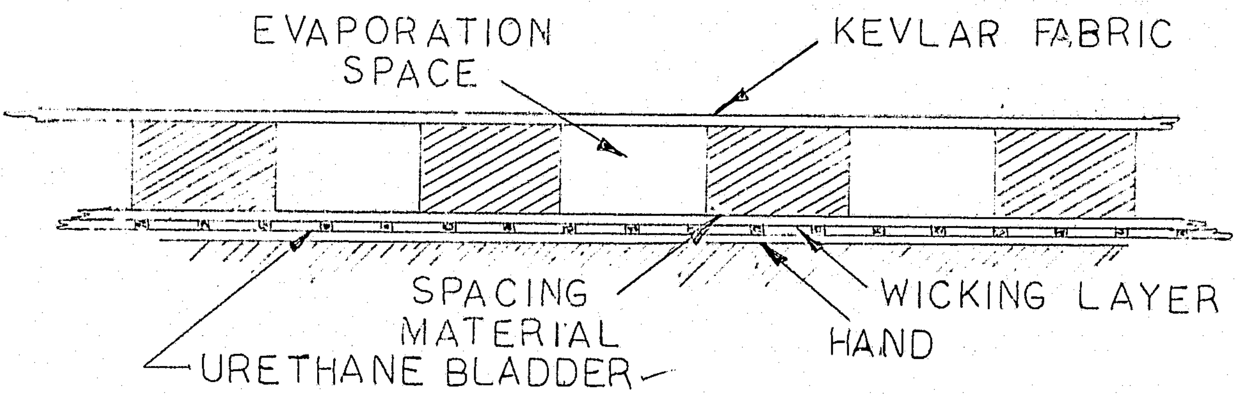

Figure 23

Material	Arrangement on Wick
1. Imitation pearls on an absorbent string	arranged in a random pattern
2. Hexagonal beads	arranged in regular rows
3. Small plastic circles	arranged in regular rows
4. Velcro nylon hook fasteners Hook #80	strips of Velcro arranged in regular rows
5. Small plastic tubes	arranged with one set of rows perpendicular to a second set of rows
6. 6001-1-1 "Space Fabric" from U.S. Rubber Co.	alternating strips of fabric and hexagonal beads. Fabric is 0.10 inch thick

Figures 24 through 27 show various designs which were tested and evaluated.

The cooling system tests went through three early phases of development. Each phase simulated to a closer degree the actual test conditions that will occur in a space environment.

In the first phase the cooling system patches were tested for average cooling rates at 212°F by fitting a saddle valve on the test patches, placing them inside a Kevlar pouch, and then enclosing the pouch in a vacuum tight poly-vinyl-chloride PVC plastic bag. The test patch could be quickly attached to a pipe, and the valve could be connected to the vacuum glove-box, Figure 28.

VELCRO COOLING PATCH

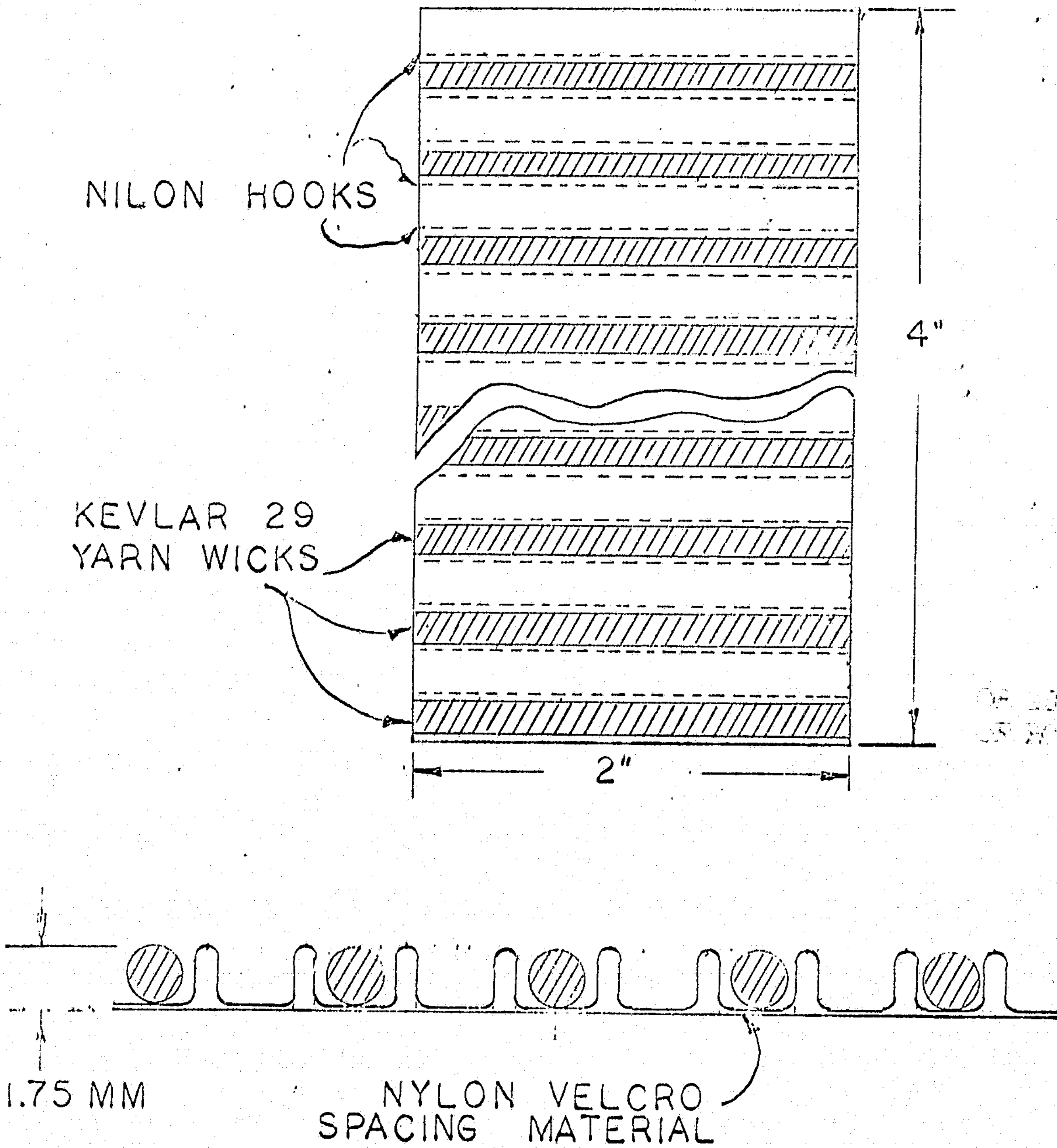

Figure 24

"SPACE FABRIC" COOLING PATCH

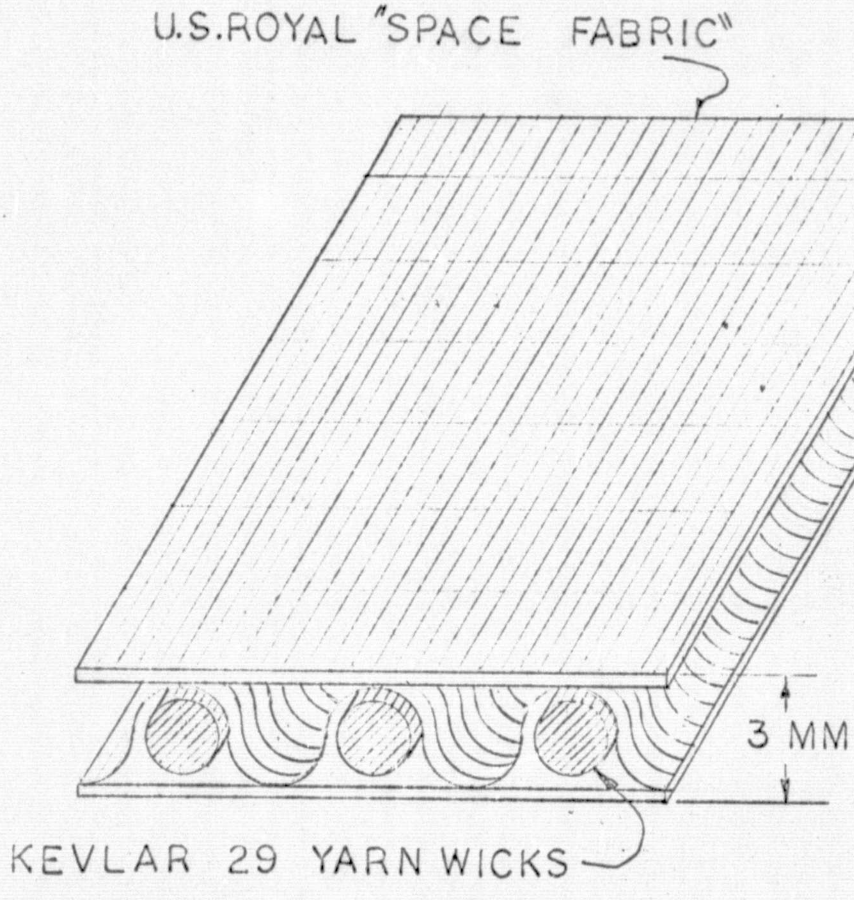

Figure 25

"SPACE FABRIC" COOLING PATCH

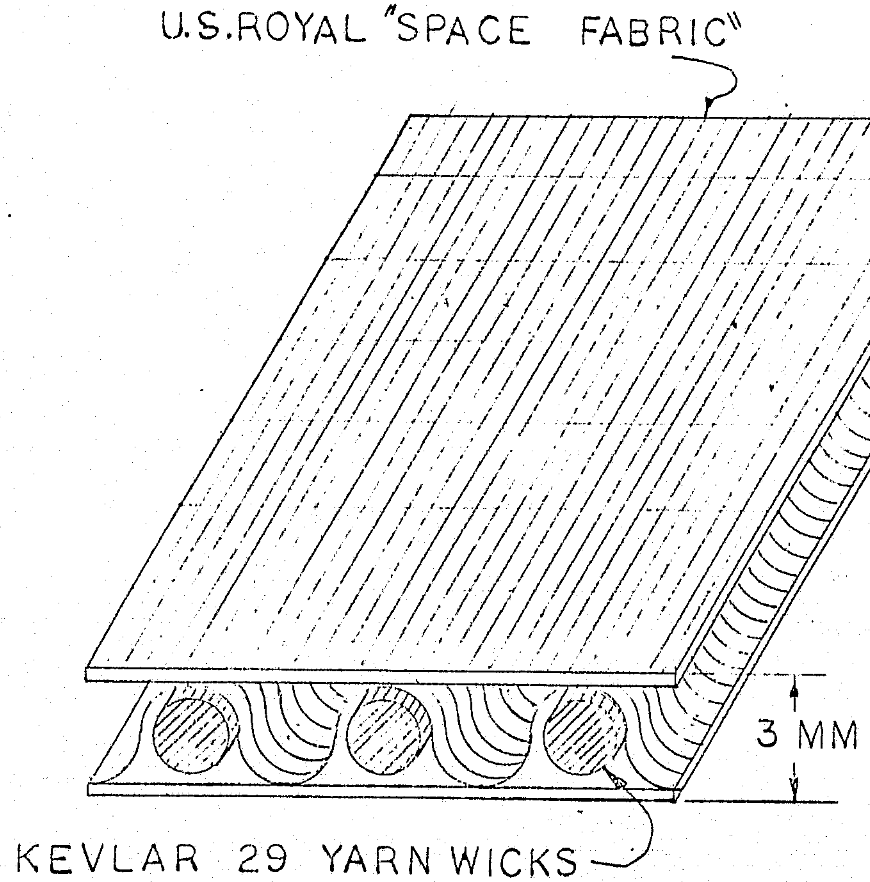

Figure 25

PLASTIC TUBING COOLING PATCH

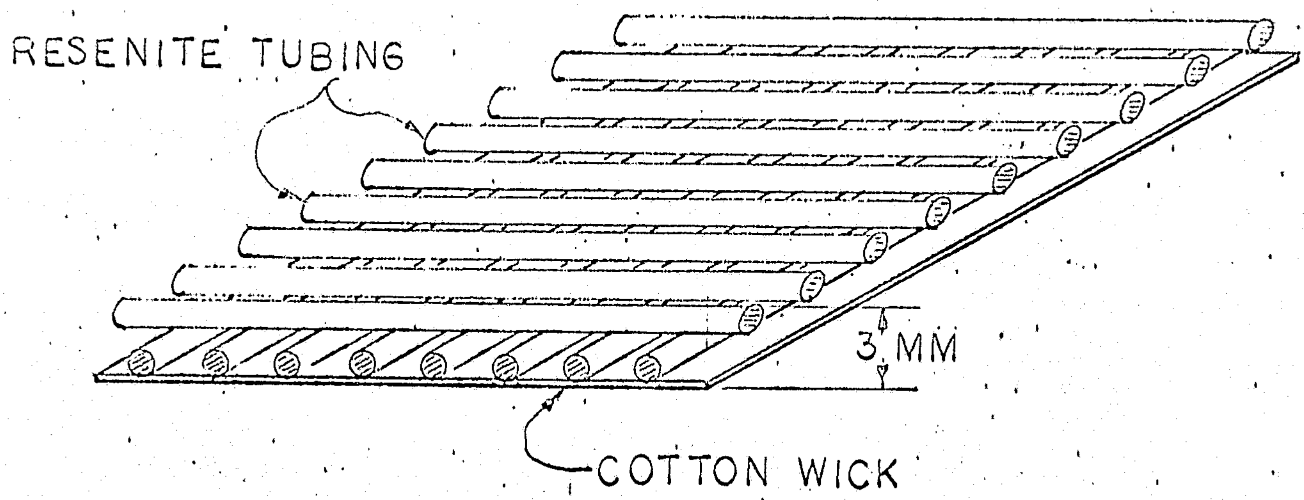

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Figure 26

TEFLON TUBING AND/OR GLASS BEAD COOLING SEGMENT

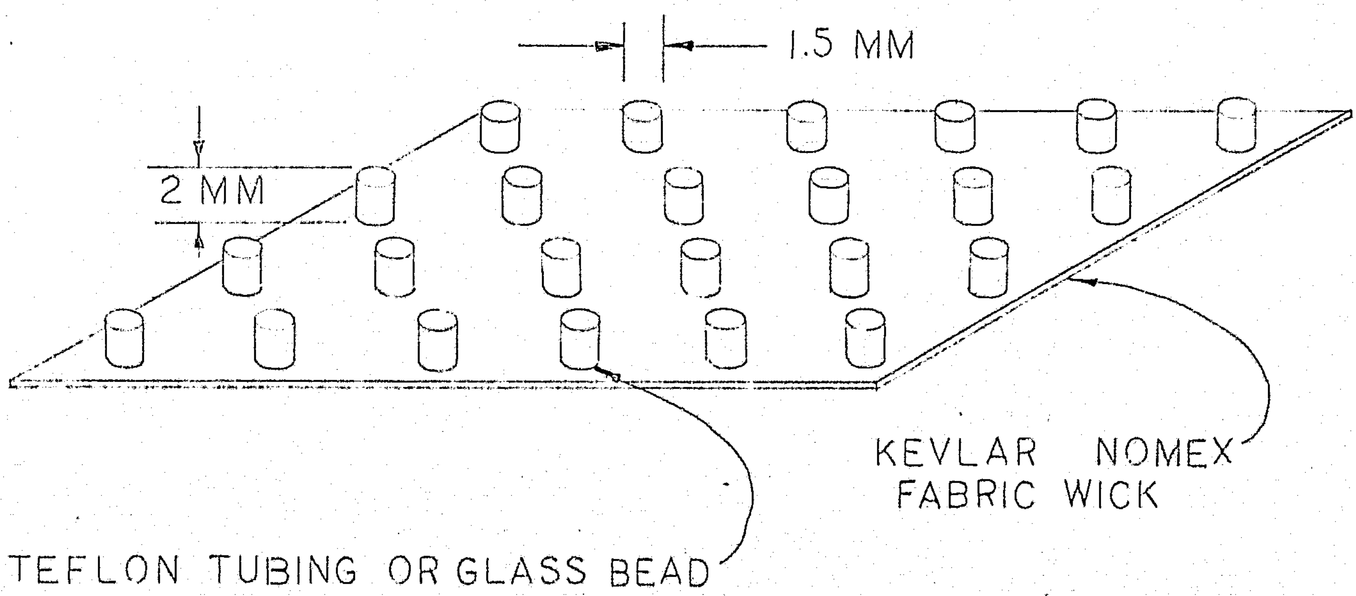


Figure 27

SCHEMATIC DIAGRAM OF PHASE ONE TEST SET-UP

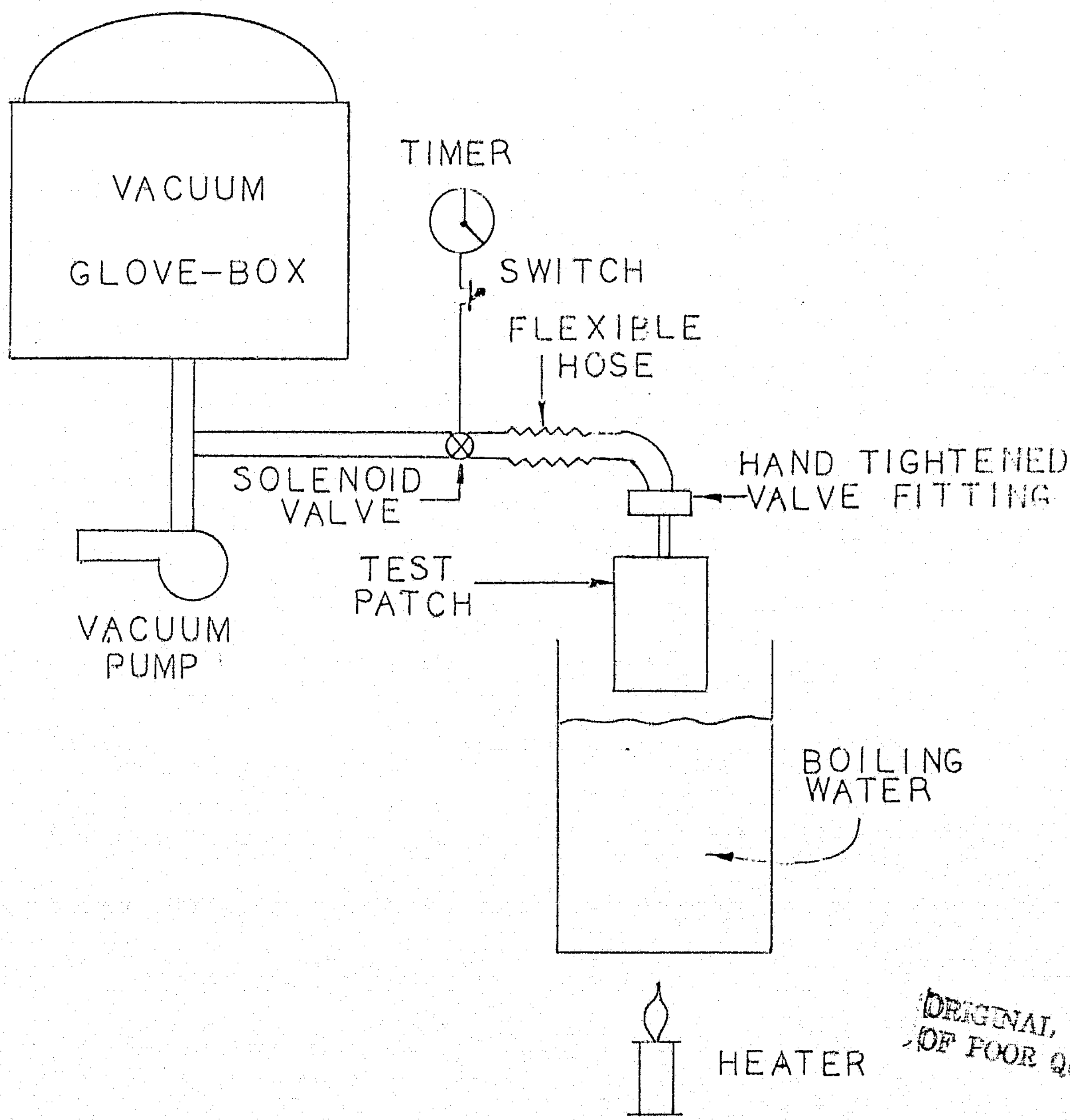


Figure 28

The test procedures were as follows. The PVC bagged cooling patch was wetted with distilled water, weighed, attached to the pipe, and immersed into boiling water (212°F). The solenoid valve was opened, evacuating the plastic bag, and starting the timer. After a brief period of time (about 8 to 13 seconds) the solenoid valve was closed which also stopped the timer. The bag containing the cooling patch to be evaluated was detached and weighed to determine the amount of water that was evaporated during the test. The cooling rate was then calculated by means of the following equations:

$$\frac{(X \text{ gms water evaporated})}{(t \text{ sec}) \quad (A \text{ in}^2)} \left(\frac{2.139 \text{ Btu}}{\text{gms water evaporated}} \right) = \frac{Y \text{ Btu}}{\text{sec-in}^2}$$

$$\frac{(Y \text{ Btu})}{\text{sec-in}^2} \; \frac{(3600 \text{ sec})}{\text{hr}} = \frac{Z \text{ Btu}}{\text{hr-in}^2}$$

where: X = gms water evaporated

t = duration of the test

A = area of the cooling patch

Problems arose, however, with this test set-up because cooling rates for the test patches were not as repeatable as desired. For instance one configuration had cooling rates of 67, 53, 31, 53, and 36 Btu/hr-in^2 on five different tests. There was also a question as to whether or not water could have been blown off some wicks instead of being evaporated off, thus giving erroneous results.

To correct this situation the test set-up was modified. A round aluminum plate (0.75 inches thick by 9 inches in diameter) replaced the boiling water as a heat source. The plate was heated in boiling water to obtain an even heating, and attain a temperature near 200°F. The plastic bag containing the cooling patch was placed on top of the plate as shown in Figure 29. An air filled plastic bag and weight was placed on top of the cooling patch to keep it uniformly flat against the plate. As before, the wick was wetted, the patch weighed, attached to the pipe, and the solenoid valve opened, evacuating the bag. The bag was weighed after each test to determine the amount of water evaporated, and calculations made to obtain cooling rates.

Two cooling patches were tested with this second phase set-up. One was constructed with teflon tubing spacers (Figure 27), and the other with no spacers. In the second case, the spacers were eliminated, and the Kevlar pouch itself served as the cooling device by simply wetting it. It was tested to determine if significant cooling rates could be obtained with a very small evaporation space. The test results are shown in the Table following. The active duration of each test was considerably longer than those of the first series, and the results were much more repeatable. Surprisingly enough, the data tended to indicate that significant cooling rates could be obtained with a very small evaporation space. However, results were questioned due to two factors. First, about 45% of the pouch's area did not contain any teflon tube spacing material. After noting relatively high cooling rates were obtained when no spacing material was used a question arose as to how much of the

SCHEMATIC DIAGRAM OF PHASE TWO TEST SET-UP

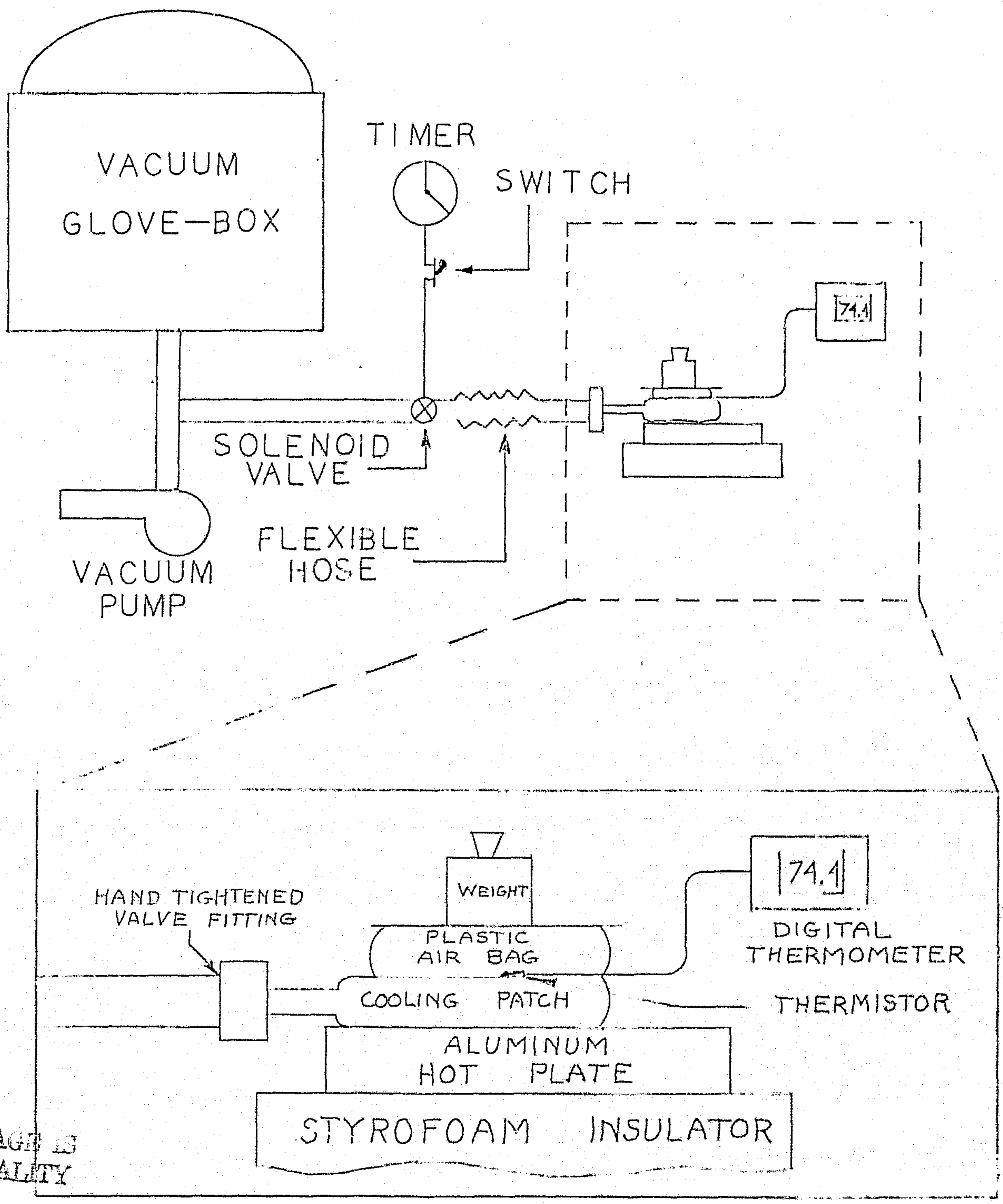


Figure 29

cooling was contributed by the edges where no spacing material was installed. Secondly, the aluminum plate temperature was somewhat questionable so it was not known if all the tests were begun at the same plate temperature. The data below was therefore used comparatively.

Spacing Material	Cooling Rate Btu/hr-in^2	Duration of Test seconds
Teflon Tubing	10.8	73
Teflon Tubing	9.6	101.7
Teflon Tubing	10.4	183
Average	10.2	
None	5.3	150
None	5.8	140
None	5.1	110
Average	5.4	

The third phase in this test program is shown in Figure 30. In this approach the testing apparatus was moved into the vacuum glove-box so as to more closely simulate the actual space conditions. The aluminum hot plate was placed on a small metal stand with thin legs to insulate its heat conduction rate to the test chamber. The cooling patch was placed in the middle of the plate, with a thermistor fastened on top to monitor its surface temperature. Another thermistor was fastened nearby to monitor the aluminum plate's surface temperature. Weighted plastic air bags were placed over both the cooling patch and the plate thermistor to insure conduction pressure equal

PHASE THREE TES

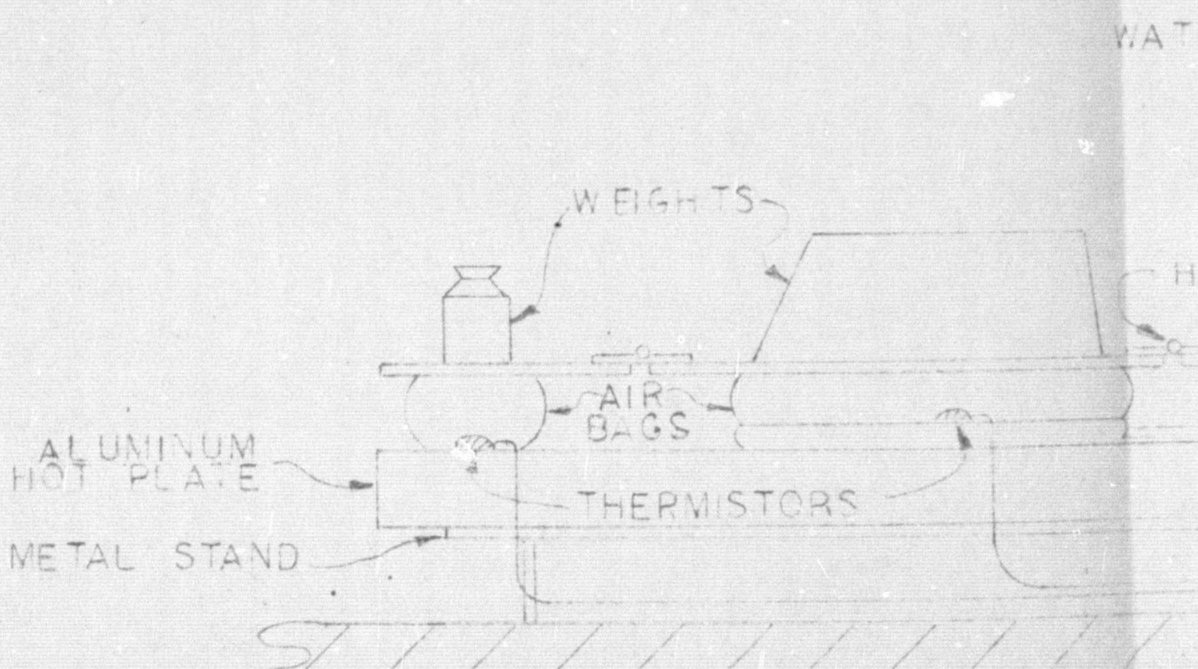
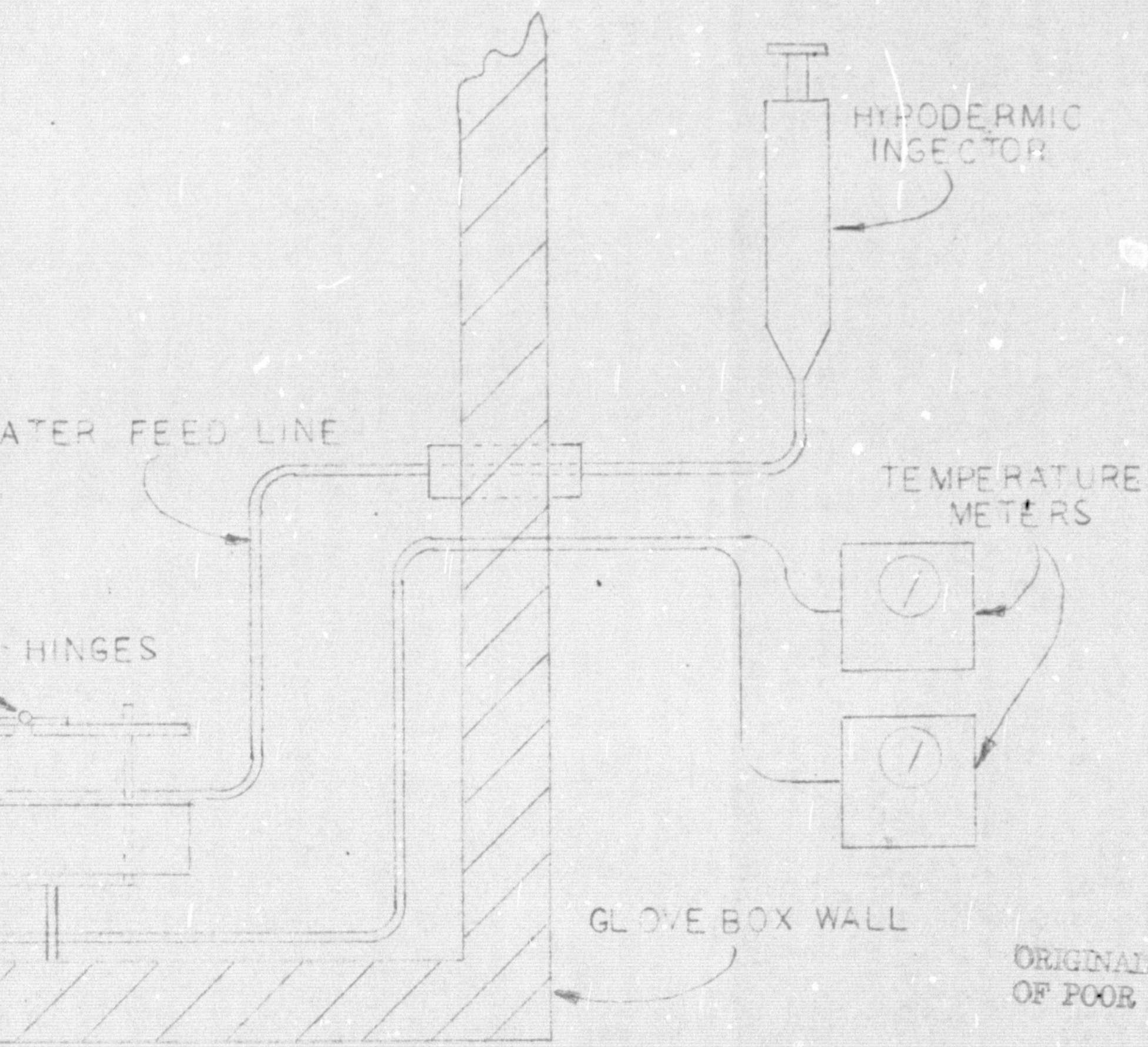


Figure 30

EST SET-UP



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to the twelve pound gripping bar. These tests were oriented to finalize the cooling system design for the prototype glove by providing data to make a decision between a cooling system using small bead spacers or one in which no spacing material is used.

In the first configuration the glass bead cooling patch was trimmed to 1.2 inches by 4 inches simulating the approximate area that would be used on the middle finger. Each bead was 2.0 mm high, and had a 2.5 mm outer diameter. It was then sandwiched between two Kevlar fabric layers. The top simulating the outer covering of the prototype EVA glove; the bottom simulating the layer closest to the urethane air bladder in the prototype. This assembly was then enclosed in a perforated PVC plastic bag which approximately simulated the thermal insulation supplied by the urethane air bladder. The edge perforations were $\frac{1}{4}$ inch holes spaced 1/10 inch apart, and simulate vapor vents that would be used along the edges of the fingers in the prototype EVA glove. In the second cooling patch, an identical area configuration was used, but here two aluminized Mylar layers (0.004 inches total thickness) were sandwiched between two Kevlar fabric layers, and enclosed in a perforated PVC plastic bag. Figure 31 presents the construction details.

The tests were conducted as follows: First, the aluminum hot plate was immersed in boiling water until its temperature stabilized; after heating it was quickly placed on its small metal stand in the vacuum glove-box; the cooling patch and related

C-2

PHASE THREE COOLING PATCHES

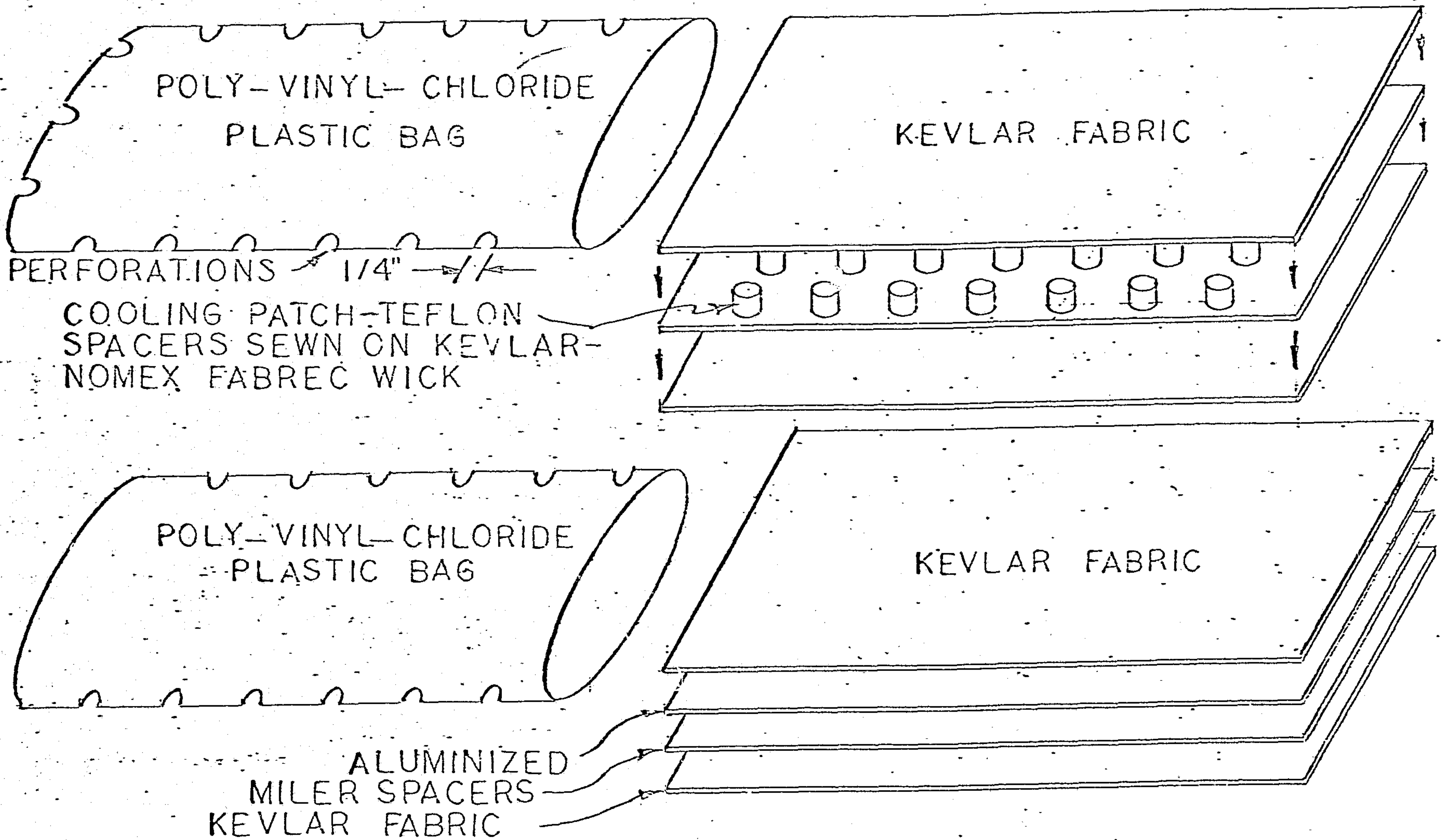


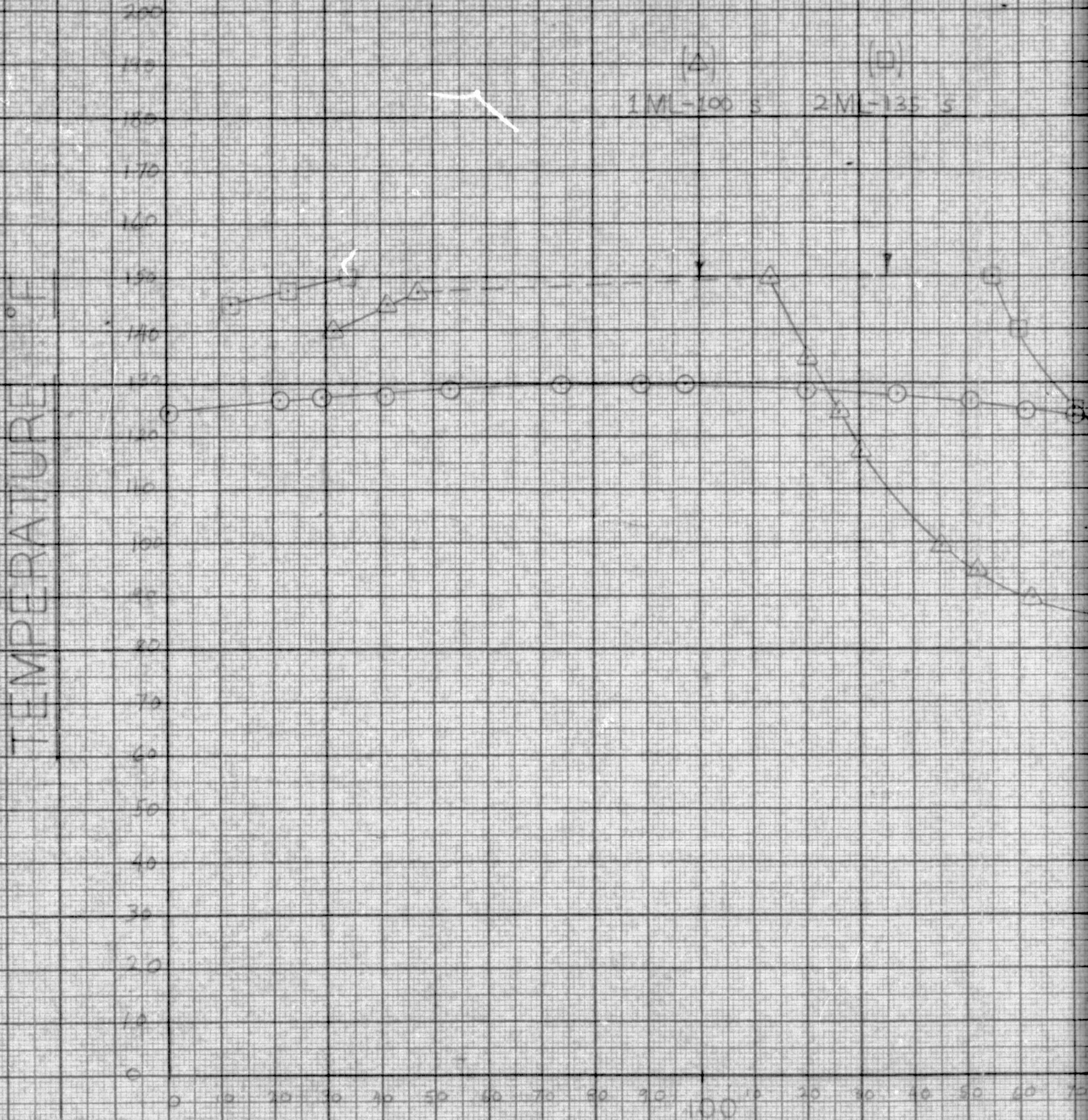
Figure 31

equipment were assembled as shown in Figure 30; and lastly, the glove-box was sealed. Test vacuum was rapidly obtained by joining the glove-box to a large vacuum chamber having its own vacuum pump by means of a fast opening valve. The time to attain test condition vacuum is given in the table below. Results have shown that cold temperatures result in just a few seconds.

Time	Pressure	Boiling Temperature
30 seconds	4.9 mm Hg	34°F
60 seconds	2000 microns	32°F
90 seconds	1000 microns	32°F
180 seconds	100 microns	32°F

After test-vacuum had been established, water was injected to the cooling patch wick by means of a hypodermic plunger located on the outside of the glove-box. One milliliter of water was injected at a time, though in the last test series two milliliters were injected to determine cooling duration with greater wick storage. Records of time, temperature, and pressure were obtained throughout each test.

Graphs of test results are shown in Figures 32 and 33. The data tends to indicate that cooler temperatures can be expected from an ECGS with bead spacers, however, in the interests of greater mobility and tactility satisfactory performance can be attained on the prototype gloves from a cooling system with no spacing material. Therefore, it was



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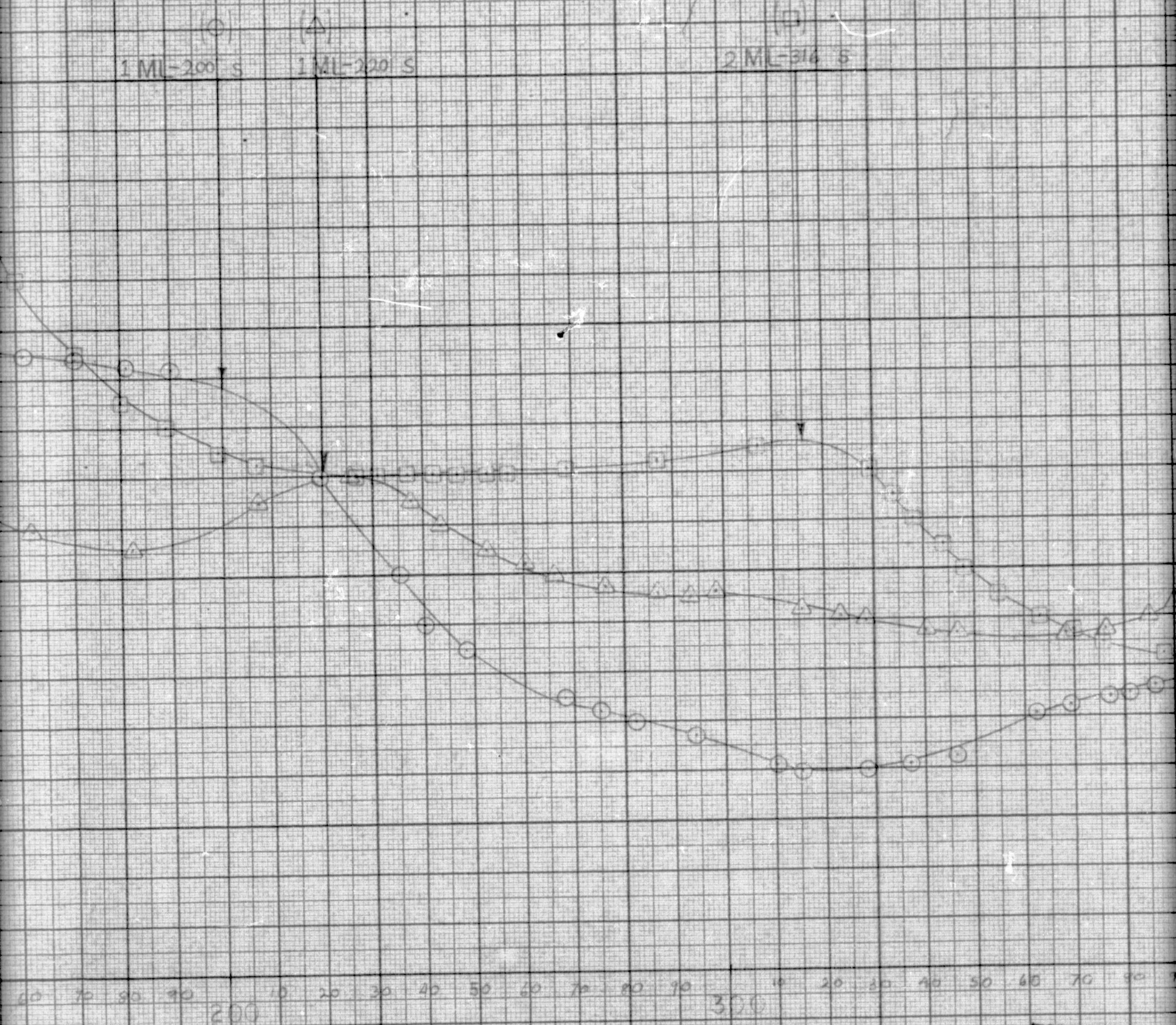
FOLD



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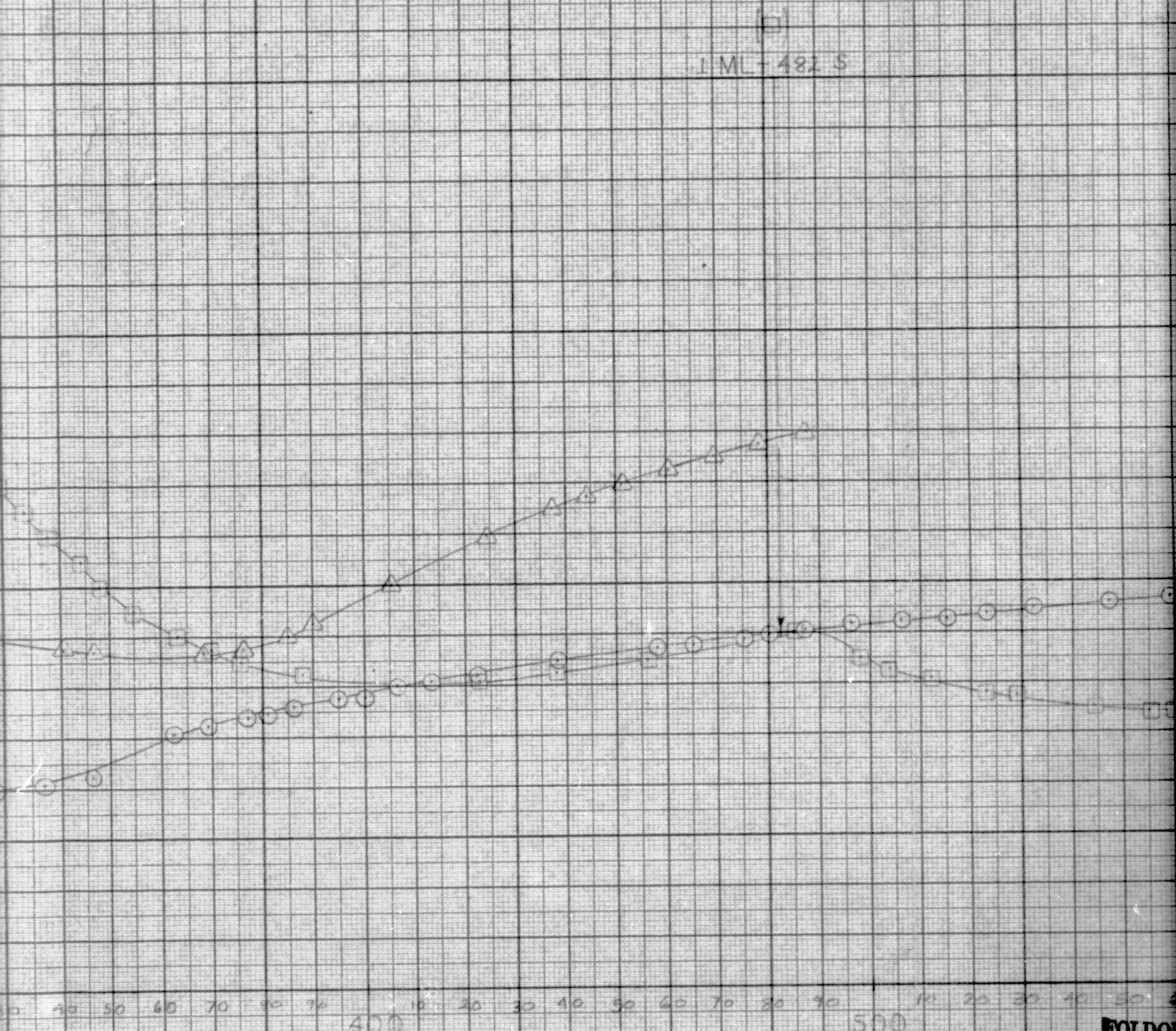
FOLDOUT FRA

ECGS COOLING PERFORMANCE

- NOTE: ARROWS CORRESPOND TO



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FOLDO

TIME . SECONDS

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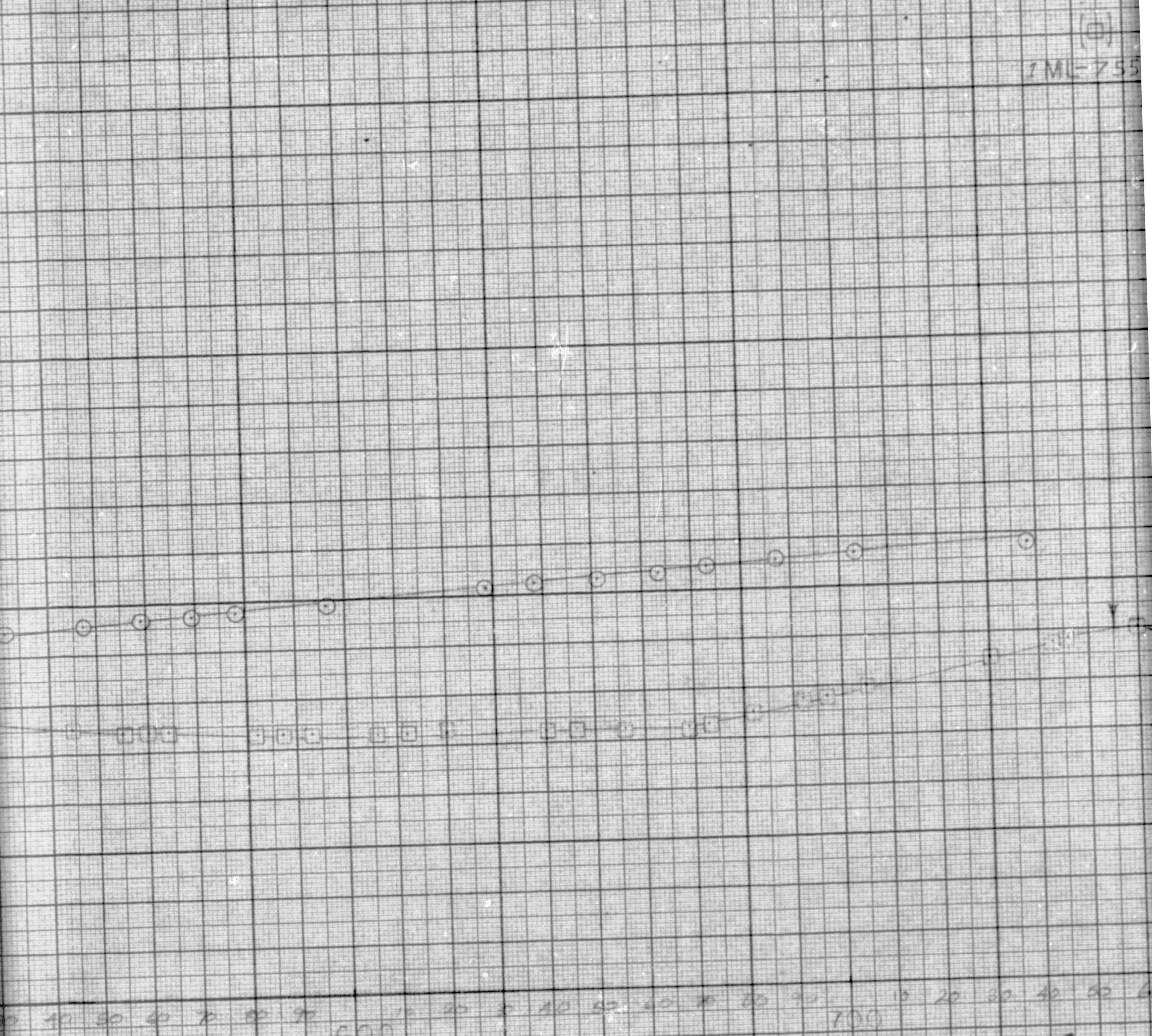
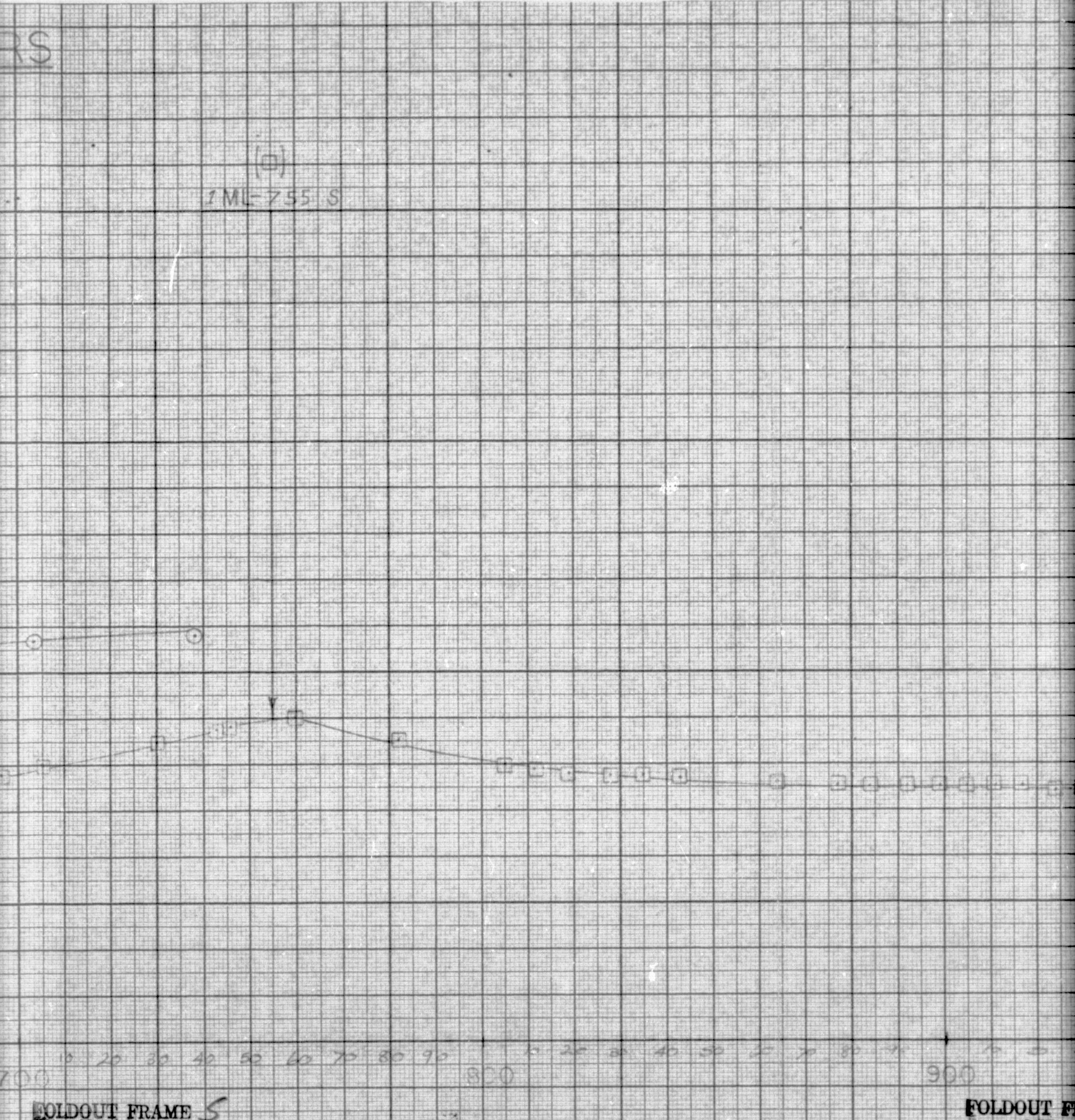
NCE WITHOUT BOILER SPACERS

OND TO H_2O INJECTIONS



OS



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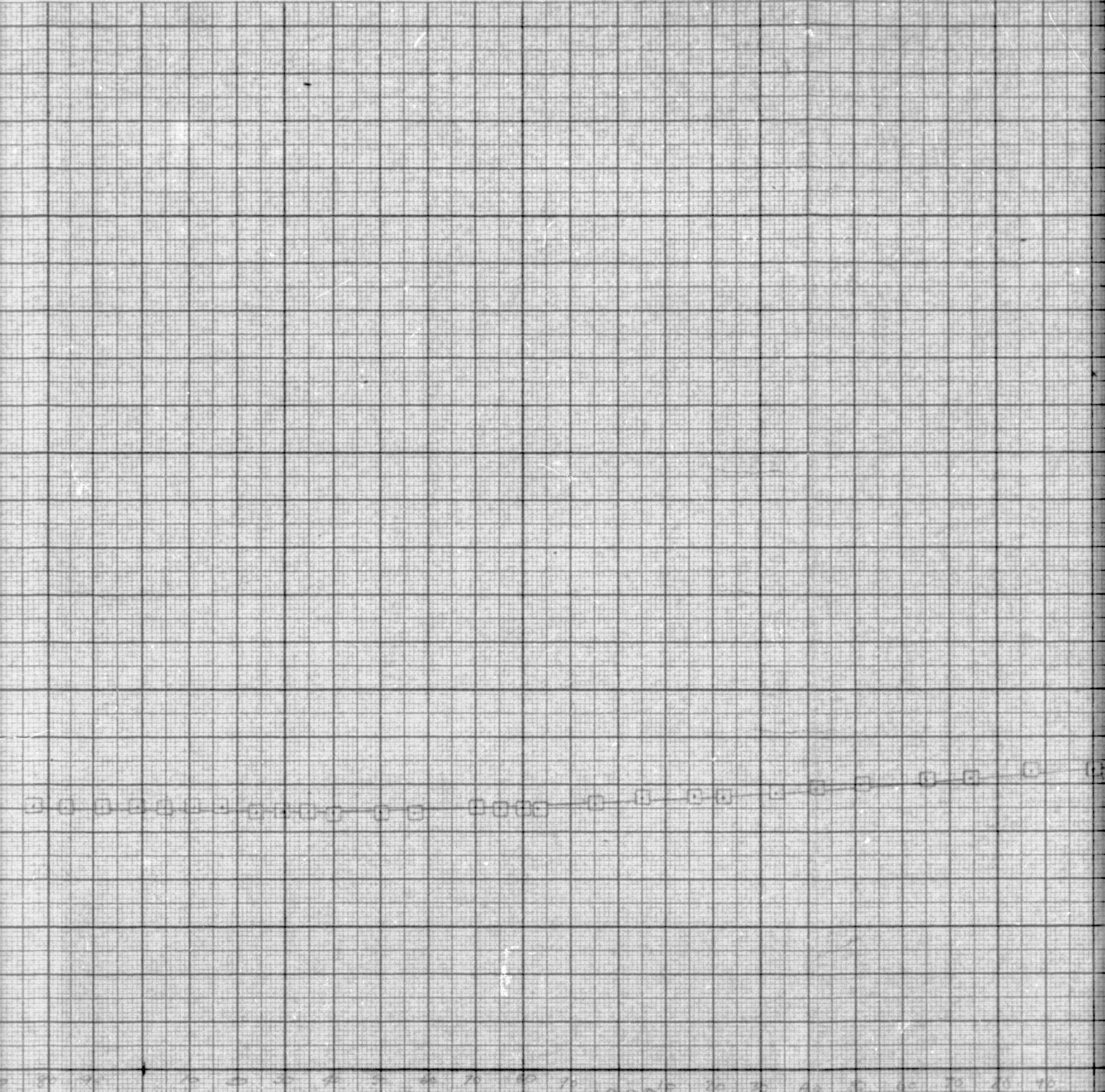

FOLDOUT FRAME 6

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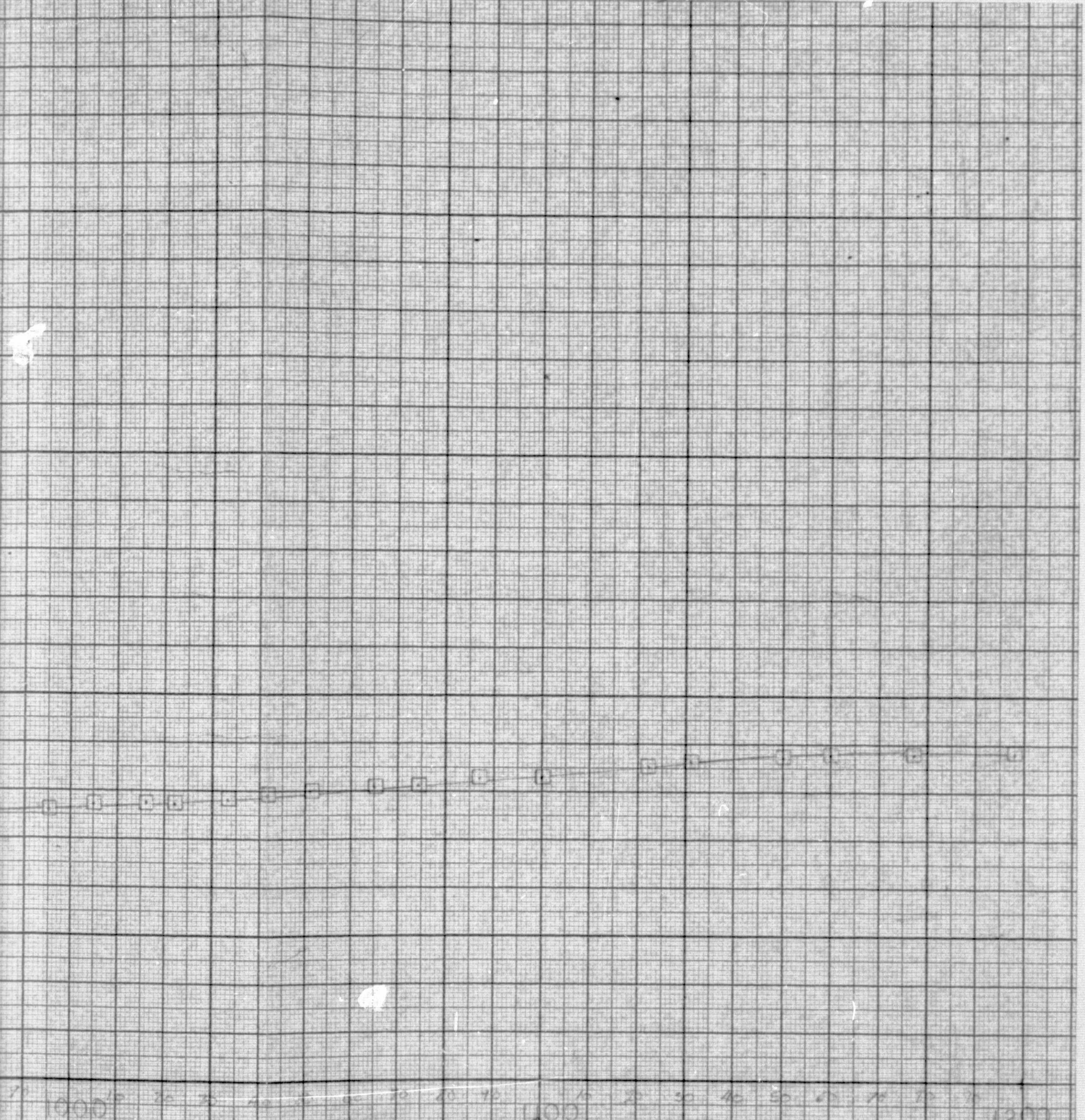

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FIGURE 32

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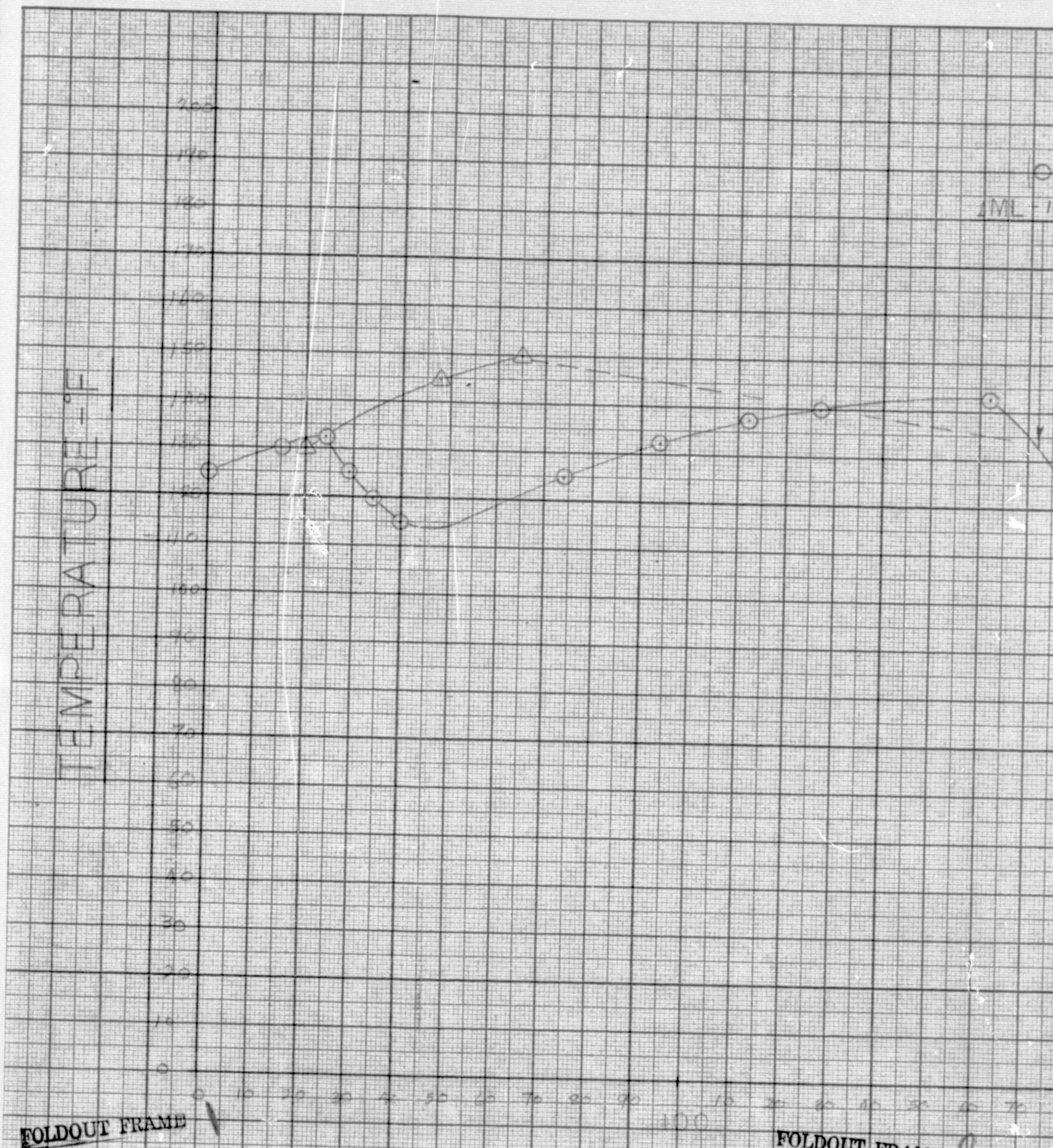

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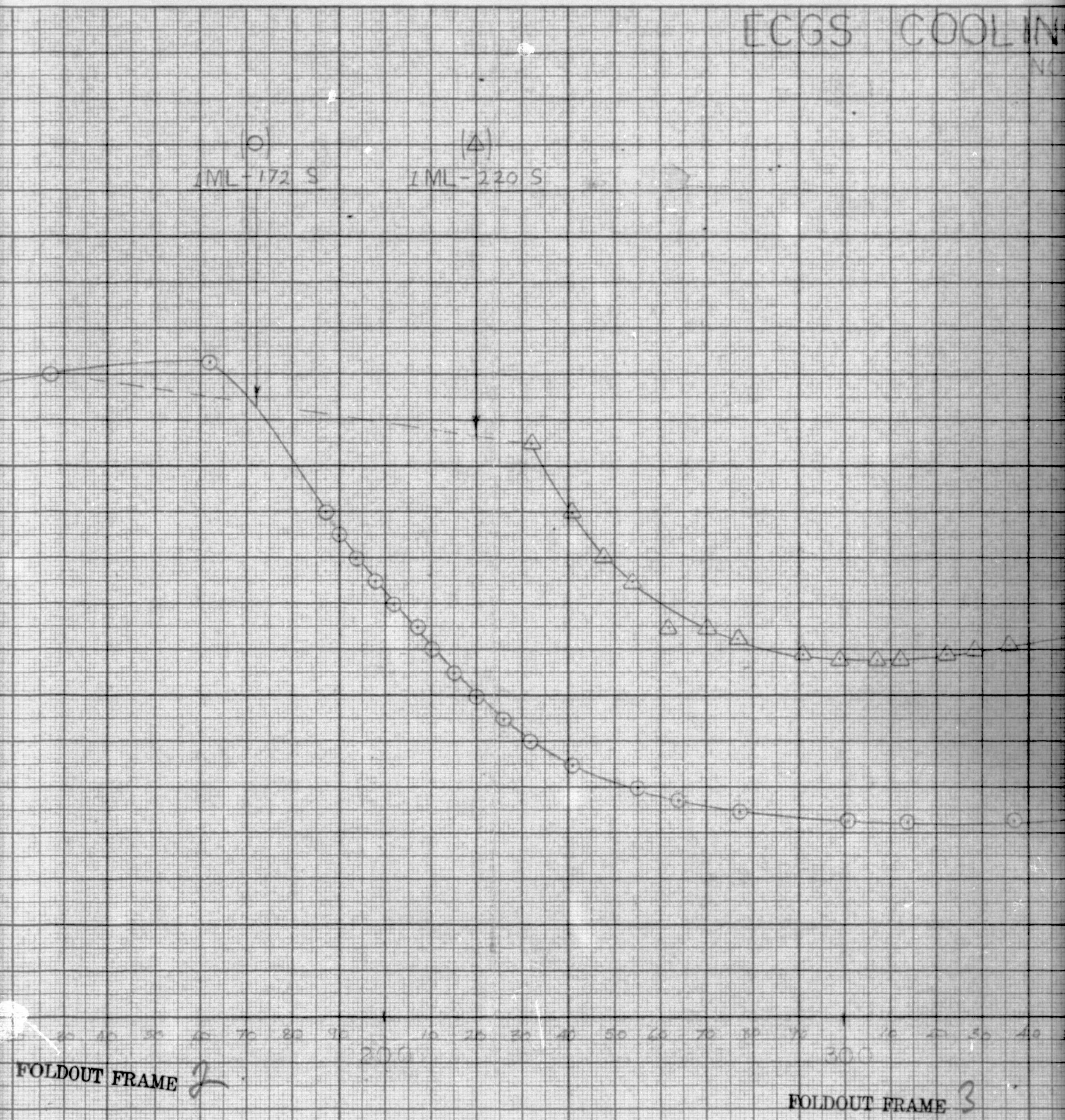

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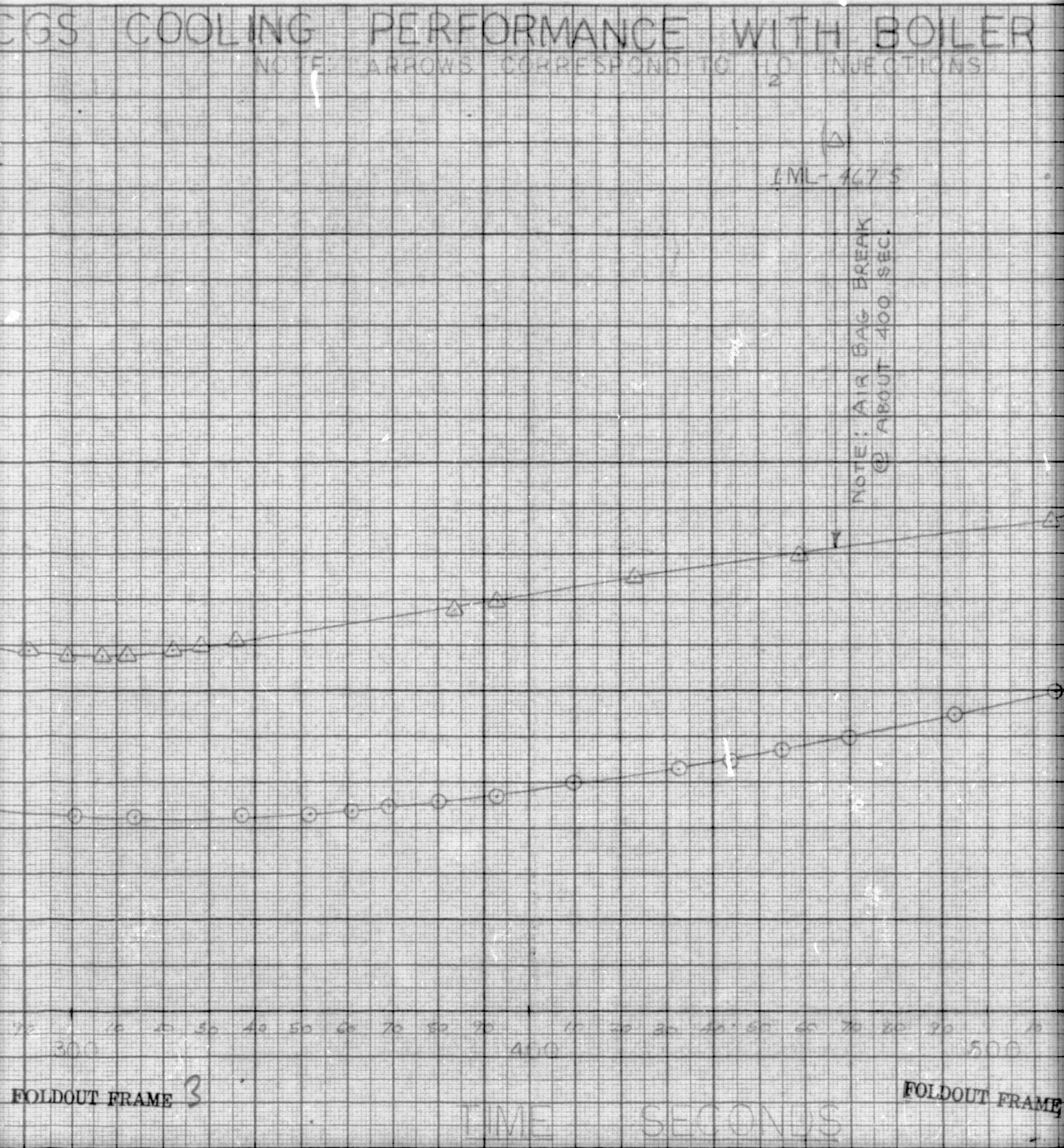
FOLDOUT FRAME 3


CGS COOLING PERFORMANCE WITH BOILER
NOTE: ARROWS CORRESPOND TO H_2O INJECTIONS
1ML - 467 S
NOTE: AIR BAG BREAK
@ ABOUT 400 SEC.
300
400
500
TIME SECONDS

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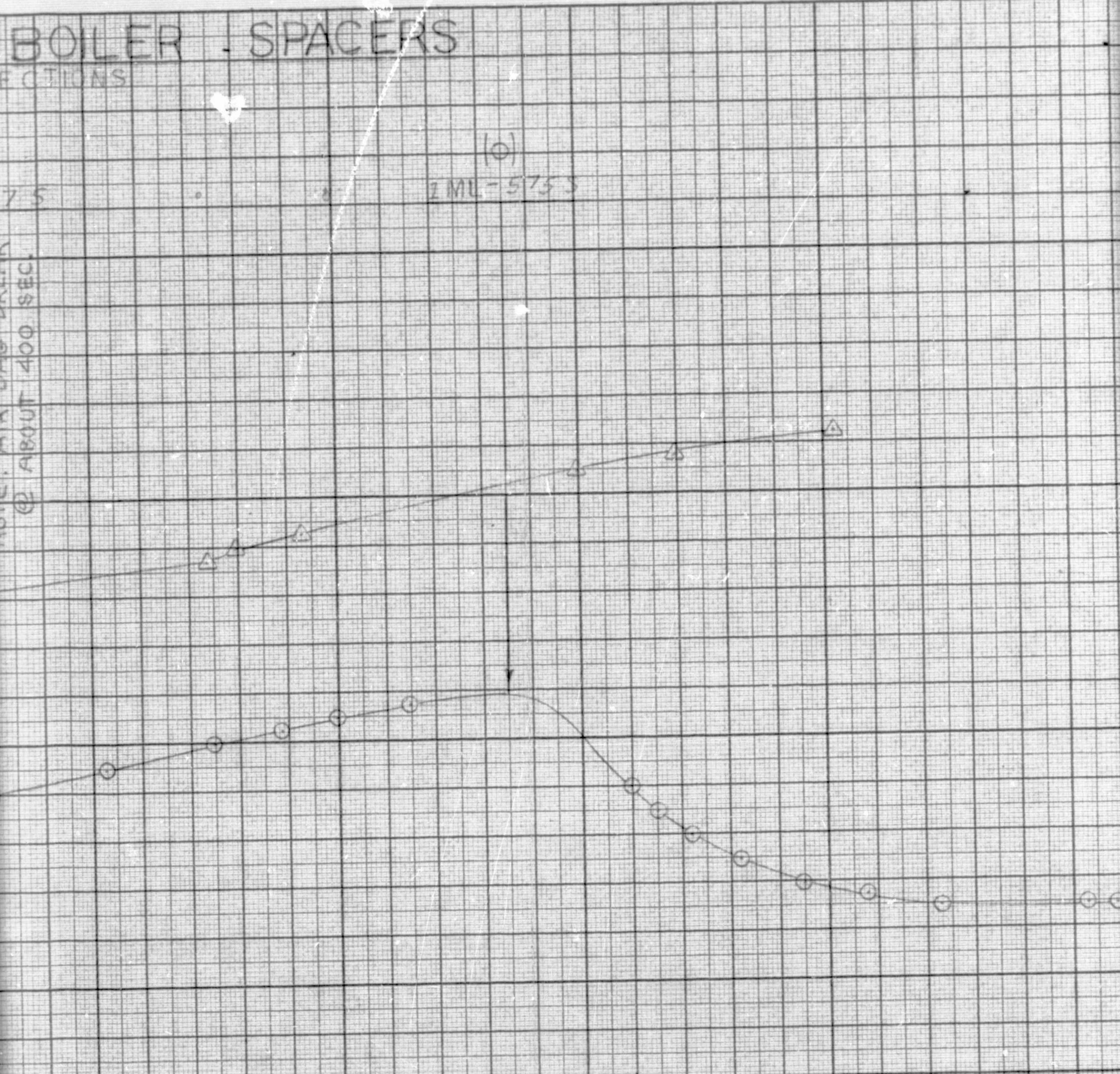

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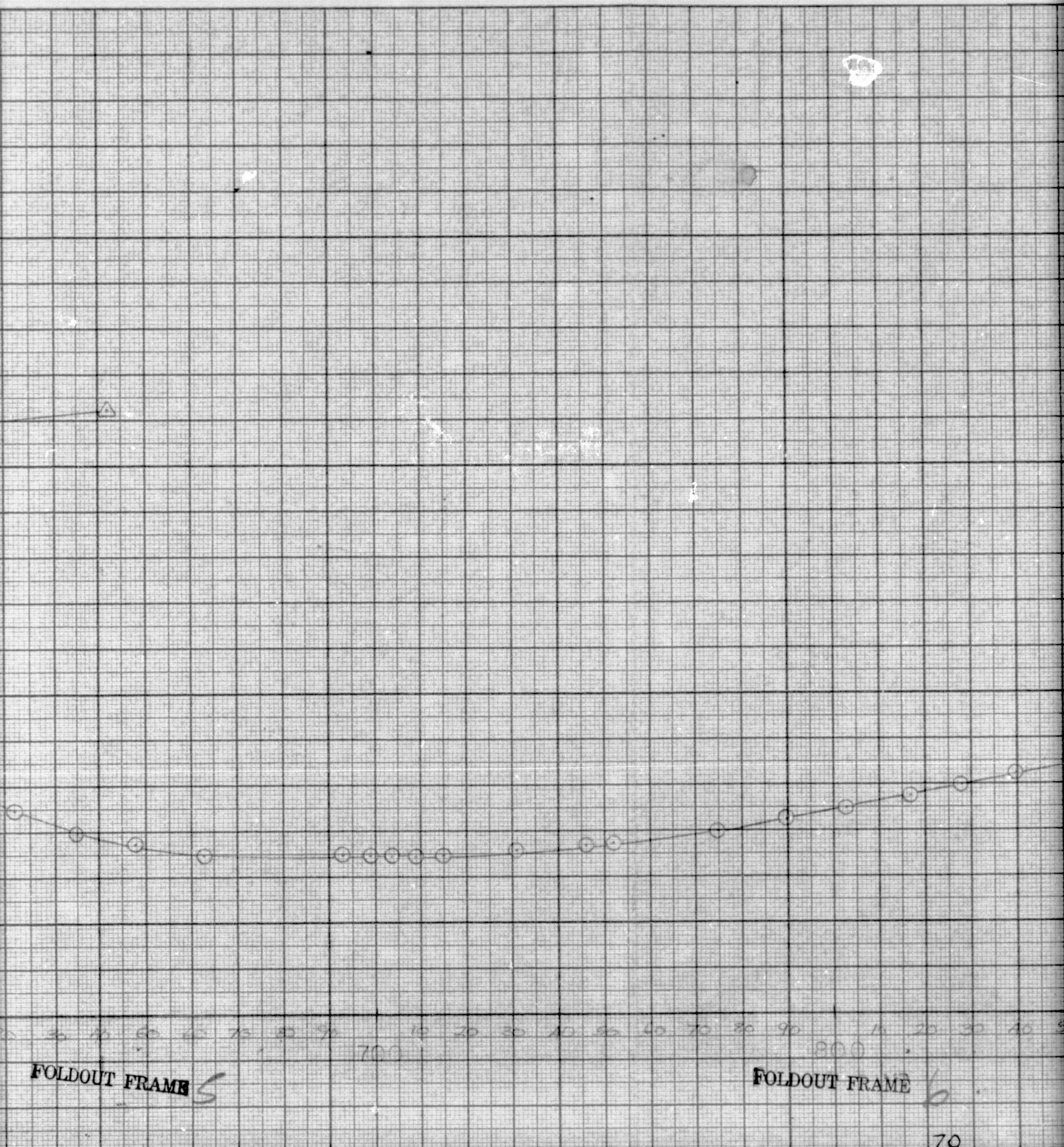

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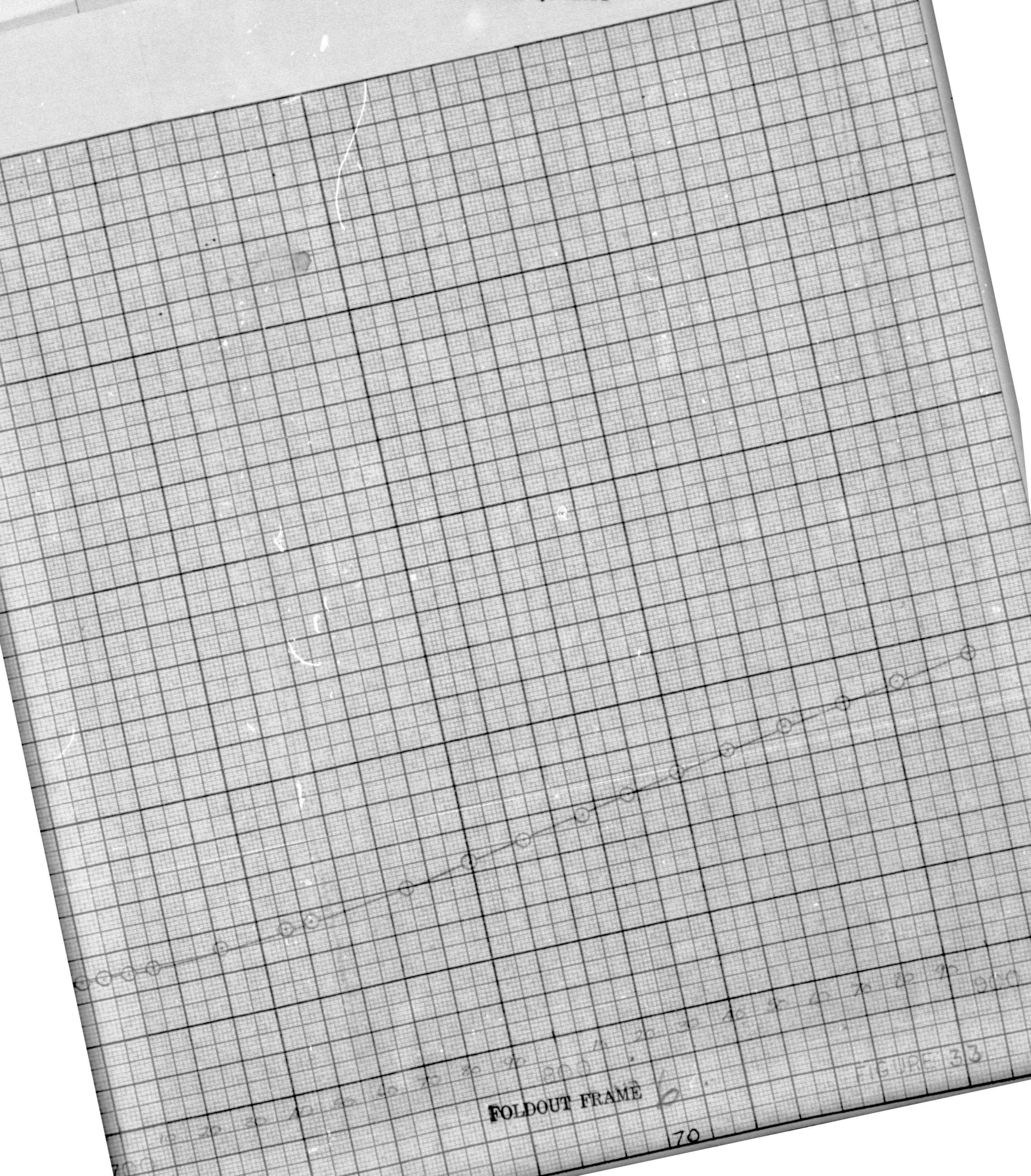

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decided to initially use the cooling system with no spacing material in the prototype glove design. The feasibility of utilizing various weaves of Kevlar as a wicking material was considered. Kevlar weavers were contacted and various samples of fabric were obtained. Qualitative tests were performed to ascertain the wicking, flexing and life-cycling characteristics of these materials. With proper cleaning, Kevlar cloths transport water by capillary rate at a rate suitable for cooling wicks. Kevlar cloth was very flexible even when saturated and kept at $0^{\circ}C - 7^{\circ}C$. Kevlar withstood more than 116,300 flexing cycles before breaking. Kevlar was utilized as a wicking material without spacers.

The data from Figures 32 and 33 were analysed, and typical, composite three-minute runs were prepared from each configuration. The results are summarized in Figures 34 and 35, each series showing that cooling would be adequate for the prototype gloves.

Water Injection Apparatus

The requirement to evaporate glove cooling water directly to space dictates water injection, as required, to the glove. Accordingly, a laboratory model of an injector system was designed and fabricated. The design and development are delineated herewith.

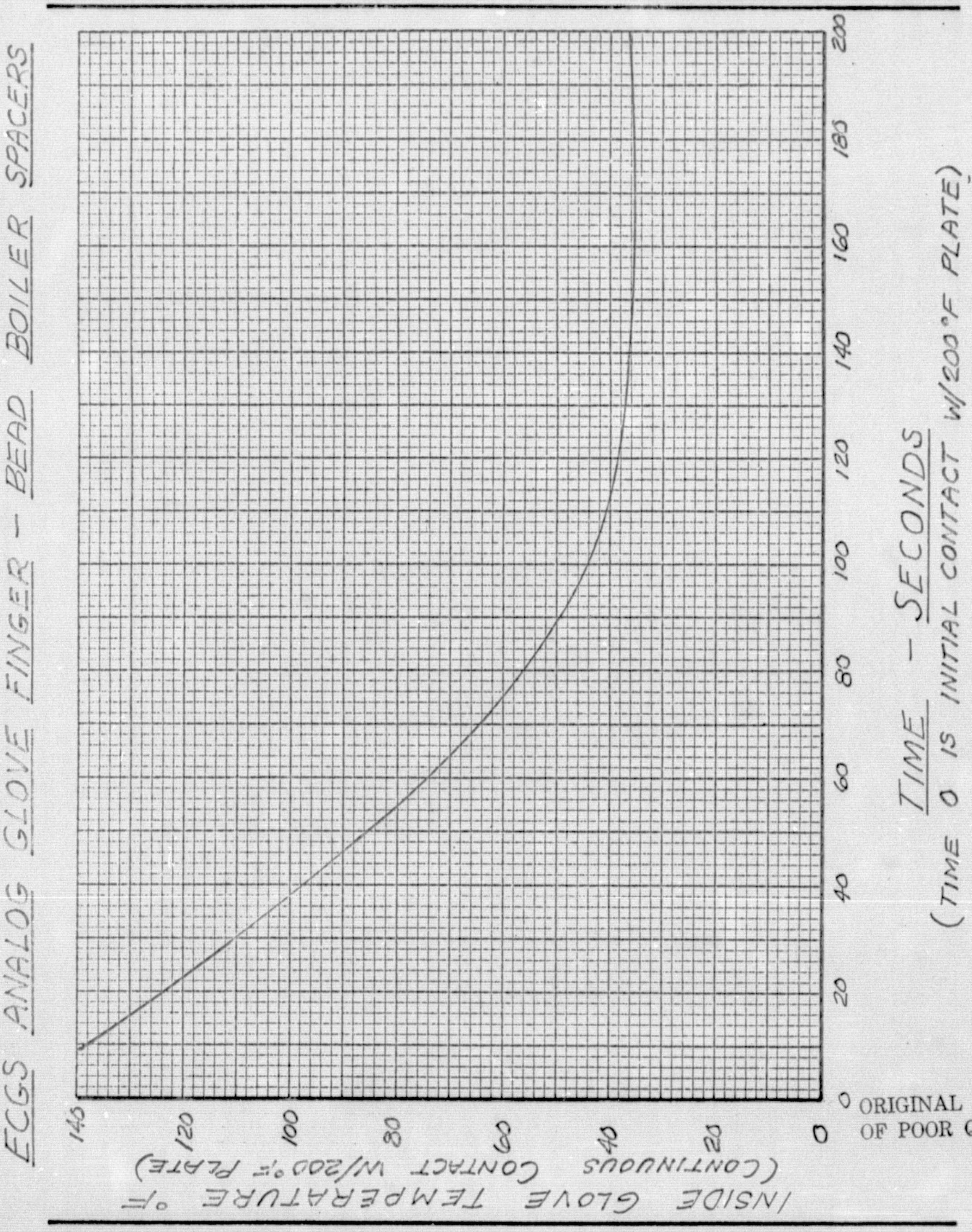
ECGS ANALOG GLOVE FINGER - BEAD BOILER SPACERS
TIME - SECONDS
(TIME 0 IS INITIAL CONTACT W/200°F PLATE)
INSIDE GLOVE TEMPERATURE °F
(CONTINUOUS CONTACT W/200°F PLATE)
0
20
40
60
80
100
120
140
160
180
200
0
20
40
60
80
100
120
140

Figure 34

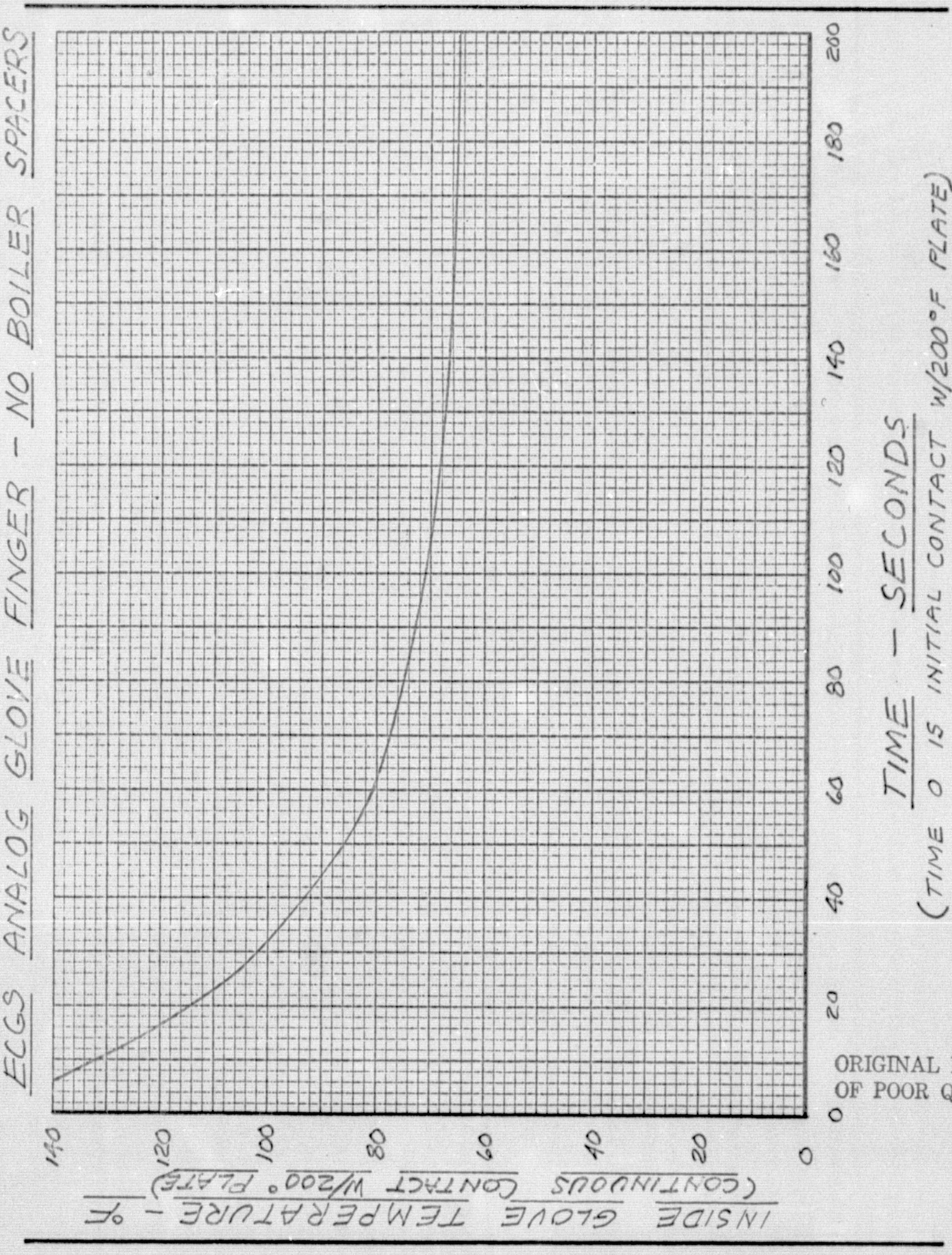

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Figure 35

A schematic diagram (with modifications) is shown in Figure 36. Power is pneumatic, and the pressure tank is self contained. A piston cylinder is used to inject the water, and the injection is completed in three steps. The first step fills the injection cylinder with water, the second injects it, and the third supplies a burst of air from the pressure tank to clear all lines of water in order to prevent freezing in the lines.

The injector assembly was used during the glove prototype tests in Houston. Temporary repairs were made at Houston to overcome injection malfunctioning.

Functional tests were performed at ERA on the water injector in a chamber set at 4 psia to determine the cause of problems found at NASA during the prototype tests on 2 and 3 July, 1975. Three factors contributed to the difficulty. Valves four and five leaked, and the plunger of the water supply tank did not move inward. The latter occurance prevented the slave injector cylinder from filling with water.

The cause of the leaks was found to be due to the type of valves, not to their malfunction. Pressure lines were connected to the output ports of the valves. The valves are three-way poppet type (input, output, and pressure relieving vent), and are designed to withstand overpressure on the inlet side only. When pressure is applied to the output port in excess of approximately 18 psia (which occurs when the entire assembly is at 4 psia) the valves relieve the overpressure through their vents. The resulting

WATER INJECTION SYSTEM

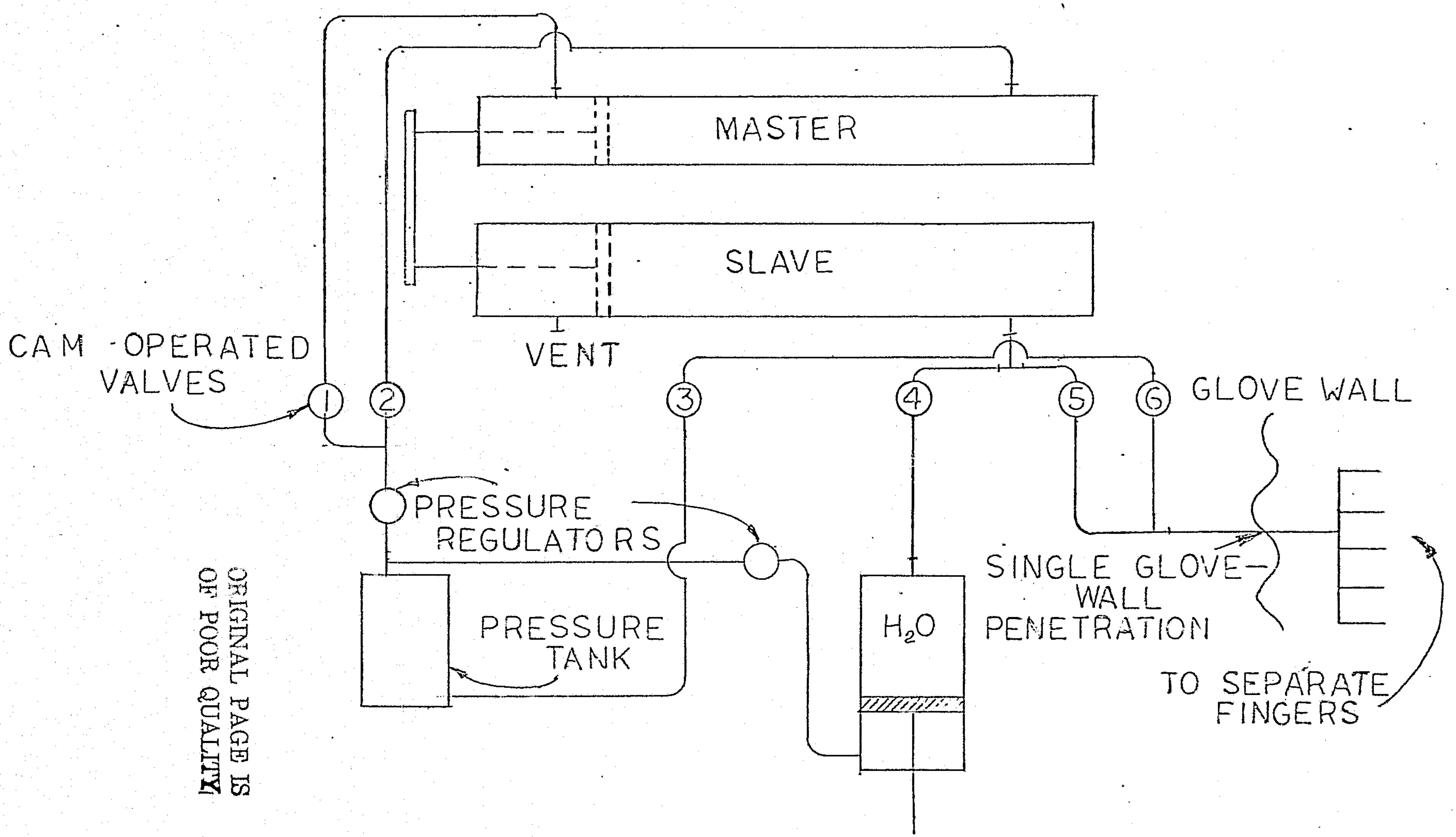


Figure 36

leakage was corrected by replacing valves four and five with two-way valves (input and output) and interchanging certain lines so that pressure is not placed on the output ports.

The plunger on the water supply tank did not move inward because the 4 psia ambient pressure was not sufficient to overcome O-ring friction. To insure proper functioning under any ambient pressure, a line was attached from the pressure tank to the vent port of the water supply tank. This new line was supplied air from a self-relieving pressure regulator. By this means a constant pressure was delivered to the water cylinder vent port which was sufficient to push the plunger inward and fill the injector cylinder regardless of ambient pressure. A schematic diagram of the water injector as modified is shown in Figure 36. The tests at Houston indicated that the cooling was too great therefore, the water flow rate produced by the injector assembly has been reduced. Furthermore, the adjusting screw which has been added to limit the water supply piston travel can be readjusted for further reduction in the flow rate.

Cooling by Conduction

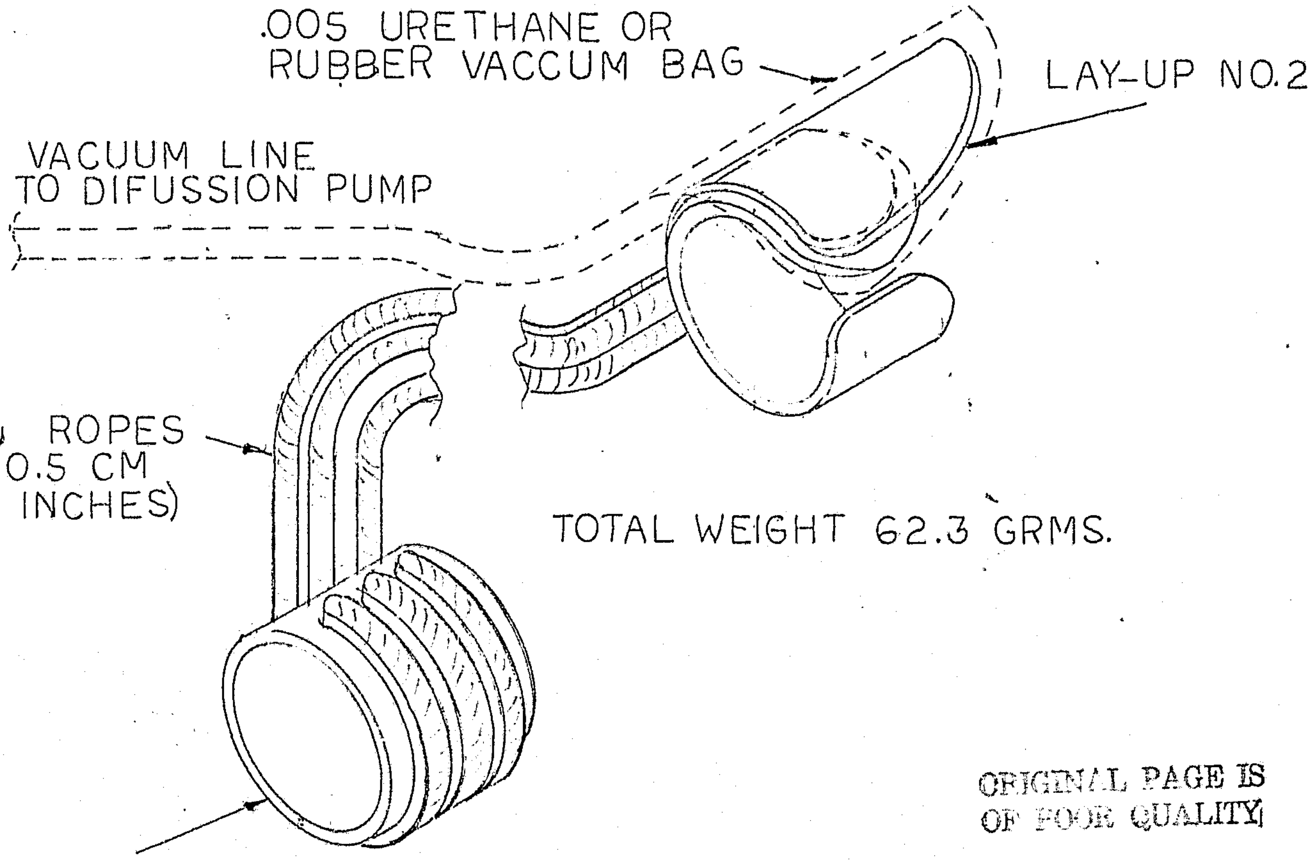
During the glove heating system development wherein the use of heat conduction from other parts of the hand to the finger areas was used it became evident that cooling of the finger areas might also be possible by the same system. Accordingly, a series of tests were made to determine the efficiency of the various designs for cooling means as well as heating means.

An early active element (heat conductors) design is shown in Figure 37. The heat sink and supply unit was air cooled. The small copper unit (layup no 2) was integrally fabricated with the insulation pads which was designed for connection to the laboratory vacuum system. Test results, while in the cooling mode, are shown in Figure 3, Manned Cooling Test vs Time. While the test subject did not report discomfort even at 300 seconds, the lay-up required a comparatively cool heat sink (79°F). Analysis of lay-ups 2 and 3 (Fig.38) following testing revealed that the Nylon netting utilized was too open weaved. As a result the combination of vacuum and 4.75 pounds per sq. in. pressure during the test allowed the Kapton layers to touch during the tests. The condition was rectified by utilizing a more closely woven Nylon (similar to the GFE comfort glove material) as a spacer for lay-up number 4.

Figure 39 shows satisfactory performance of lay-up number 4 in the cooling (Hot Bar) modes of operation. Figure 39 indicates man-system equilibrium at 114.8°F at about 240 seconds, with the finger temperature just crossing the "pain threshold" temperature of 114°F at 180 seconds. While "quite warm," the subject stated that he could continue past the 300 second mark. Thus the low rate of change of temperature achieved prevented triggering a pain sensation.

The successes noted above led to concepts utilizing the hand dorsal surface as an intermediate thermal storage and physiological transfer point, Figure 40.

FINGER TEST PAD LAY-UP NO. 2
CONFIGURATION II



LAYERS FOR LAY UP NO. 2 AND 3

COMFORT GLOVE
RUBBER GLOVE
.005 URETHANE OR RUBBER VAC. BAG

VACUUM LAYERS:
- PERFORATED COPPER
- COPPER FAN (X FER) 3 ROPES
- KA GOLD TO FINGER
- NYLON NET
- KA GOLD TO FINGER

.005 URETHANE OR RUBBER
KEVLAR 29 (GFE)

Figure 37

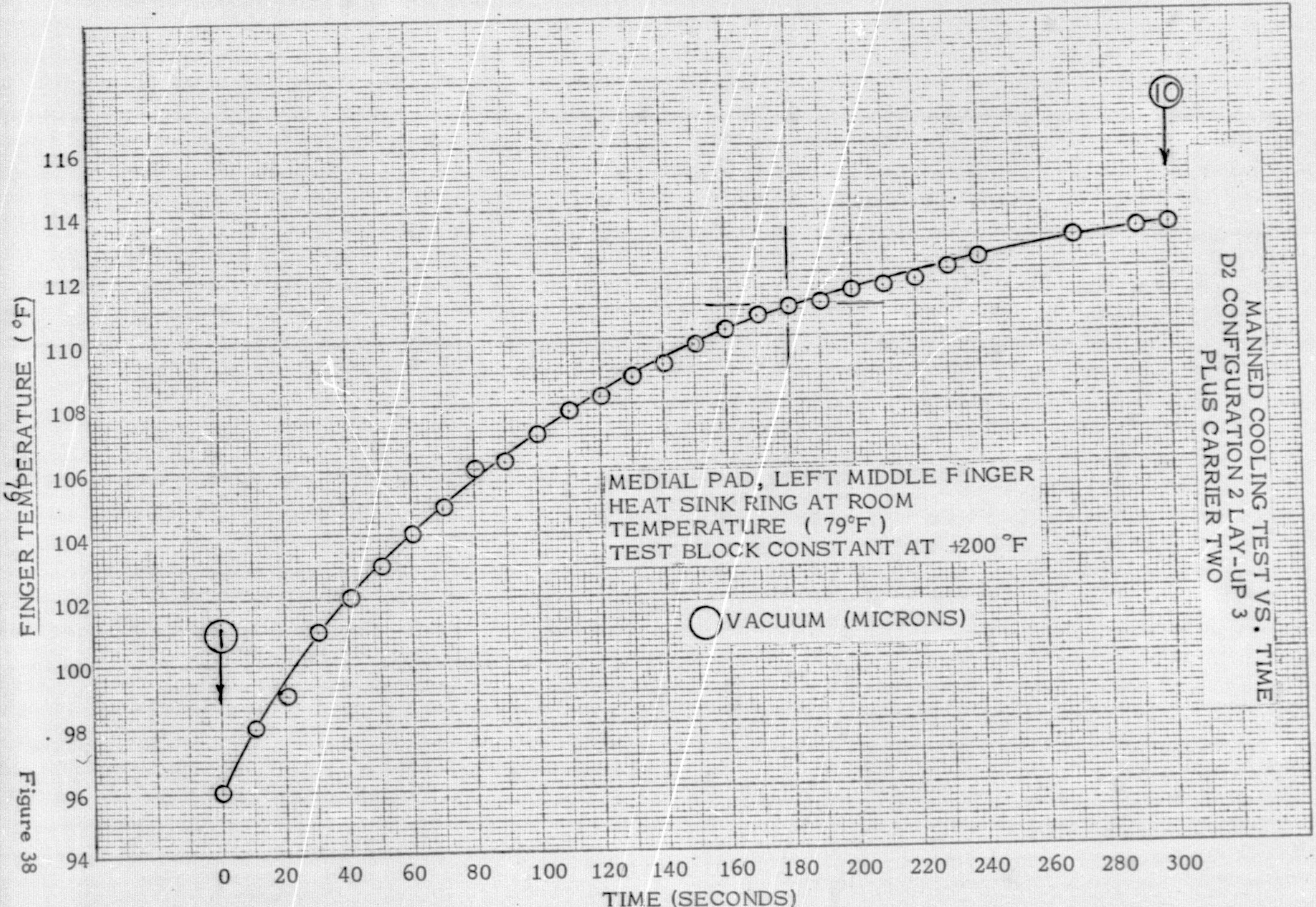

MANNED COOLING TEST VS. TIME
D2 CONFIGURATION 2 LAY-UP 3
PLUS CARRIER TWO
MEDIAL PAD, LEFT MIDDLE FINGER
HEAT SINK RING AT ROOM
TEMPERATURE (79°F)
TEST BLOCK CONSTANT AT +200 °F
VACUUM (MICRONS)
1
10
FINGER TEMPERATURE (°F)
TIME (SECONDS)
94
96
98
100
102
104
106
108
110
112
114
116
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300

Figure 38

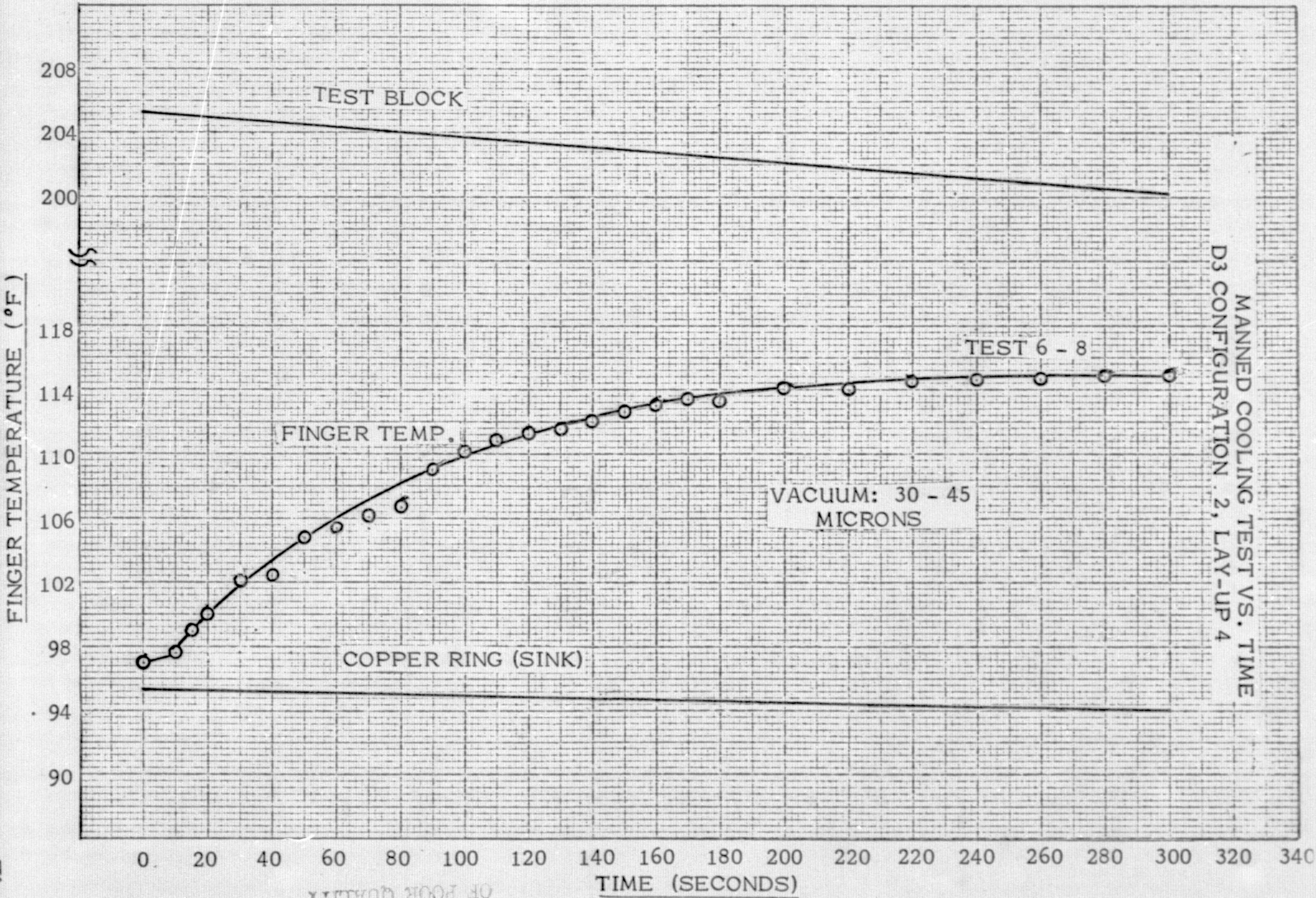

MANNED COOLING TEST VS. TIME
D3 CONFIGURATION .2, LAY-UP 4
TEST BLOCK
TEST 6 - 8
FINGER TEMP.
VACUUM: 30 - 45
MICRONS
COPPER RING (SINK)
FINGER TEMPERATURE (°F)
208
204
200
118
114
110
106
102
98
94
90
TIME (SECONDS)
0
20
40
60
80
100
120
140
160
180
200
220
220
240
260
280
300
320
340

Figure 39

FINGER TEST PAD LAY-UP NO.6
CONFIGURATION I

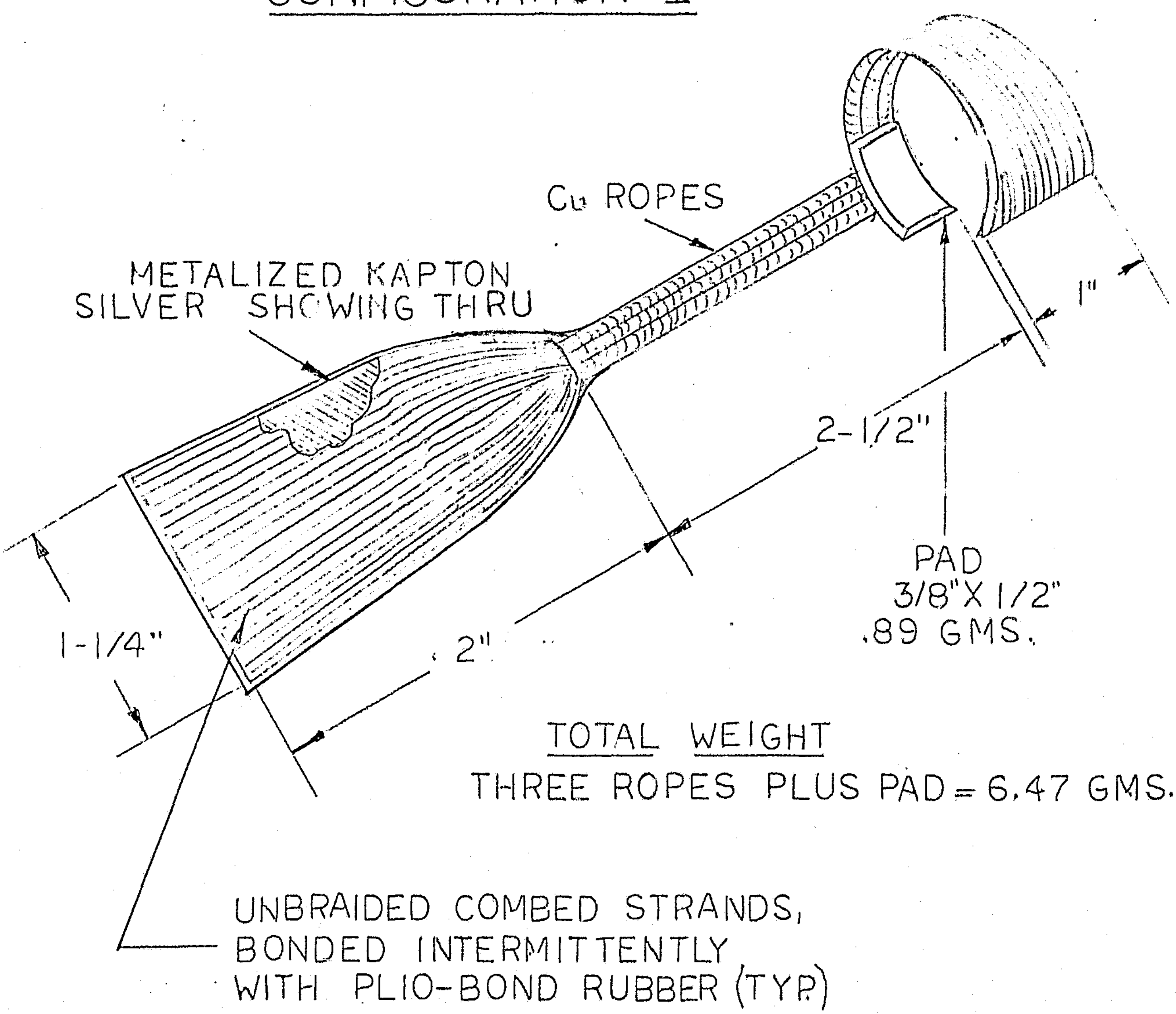


Figure 40

A cross sectional diagram showing placement on a finger pad and a typical vacuum test patch is presented in Figure 41 Cross Section, Manned Finger Tests. Test data for the cooling(Hot Bar) is shown in Figure 42, Manned Cooling Test vs Time. The finger temperature was maintained under 111°F at 180 seconds and under 113°F at 300 seconds.

The above tests had demonstrated that fine flexible copper wire pads (fans), placed in contact with the skin, could act as heat sinks and also as active transport elements, allowing the blood circulation to dissipate the heat. A series of tests, (A) through (F), was run to determine which skin areas and fan configurations would be most efficient. The hot block temperature varied for this series of tests from +204°F to +198°F. The vacuum levels in the insulation pad during these tests varied from less than one micron to 16.9 microns.

All tests were run with a layer of comfort glove (GFE) next to the skin and a layer of comfort glove plus a rubber sheet (to simulate the rubber membrane) covering the fan arrangements. The standard MP-2 insulation pad, Figure 43 was used on all tests. The finger was pressed on the hot plate with a force of 3.7 pounds. This series of tests is presented in Figure 45.

All tests were run with fans made from very flexible, pure copper wire (99.99%). The "ropes" (Figure 44) are 16 gauge wire with a 2660 circular mil area. These wires are comprised of seven wires, each of which is made up of three wires, in turn comprised of about 32 wires, .002 in. diameter wires.

CROSS SECTION, MANNED FINGER TESTS (TYP.)

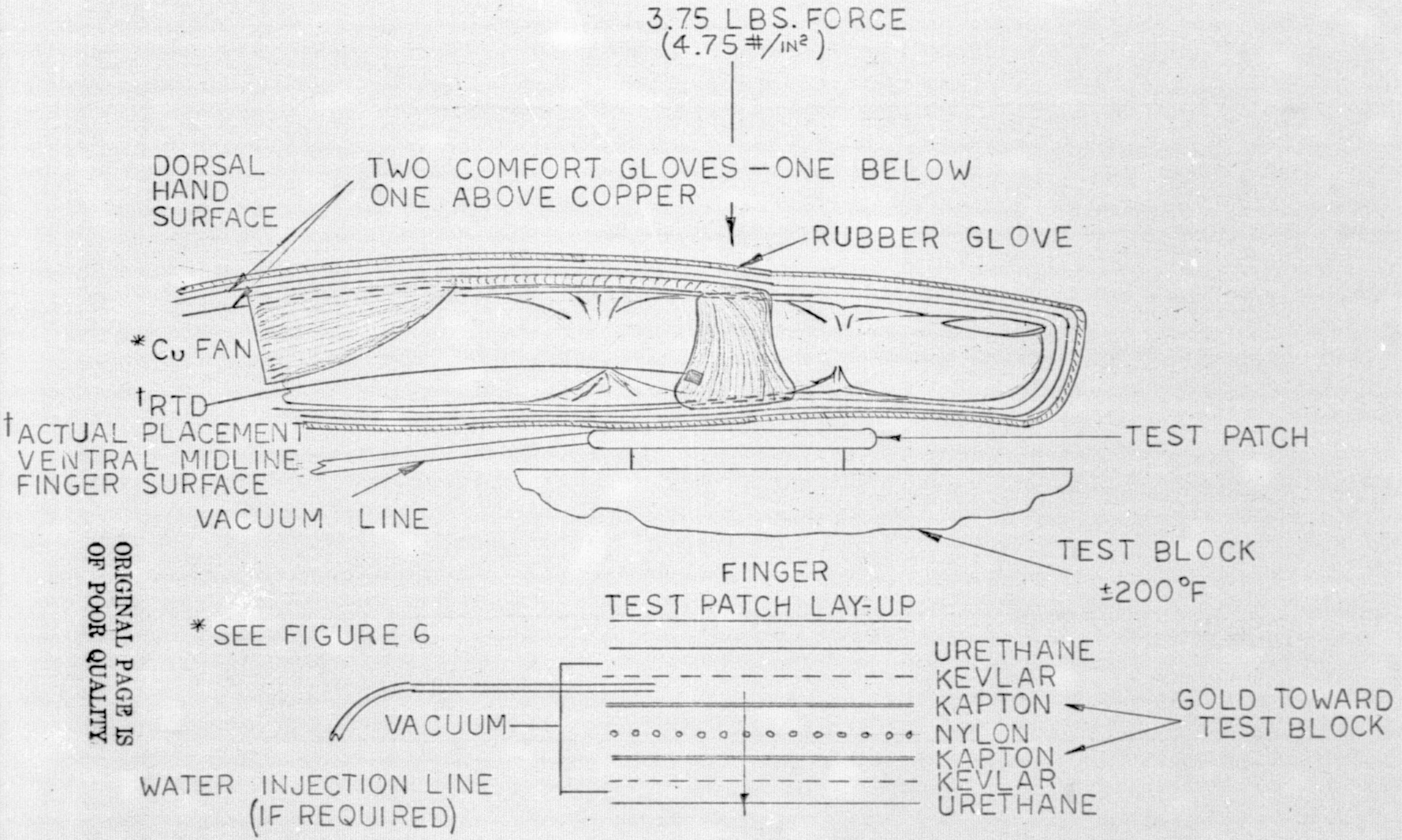


Figure 41

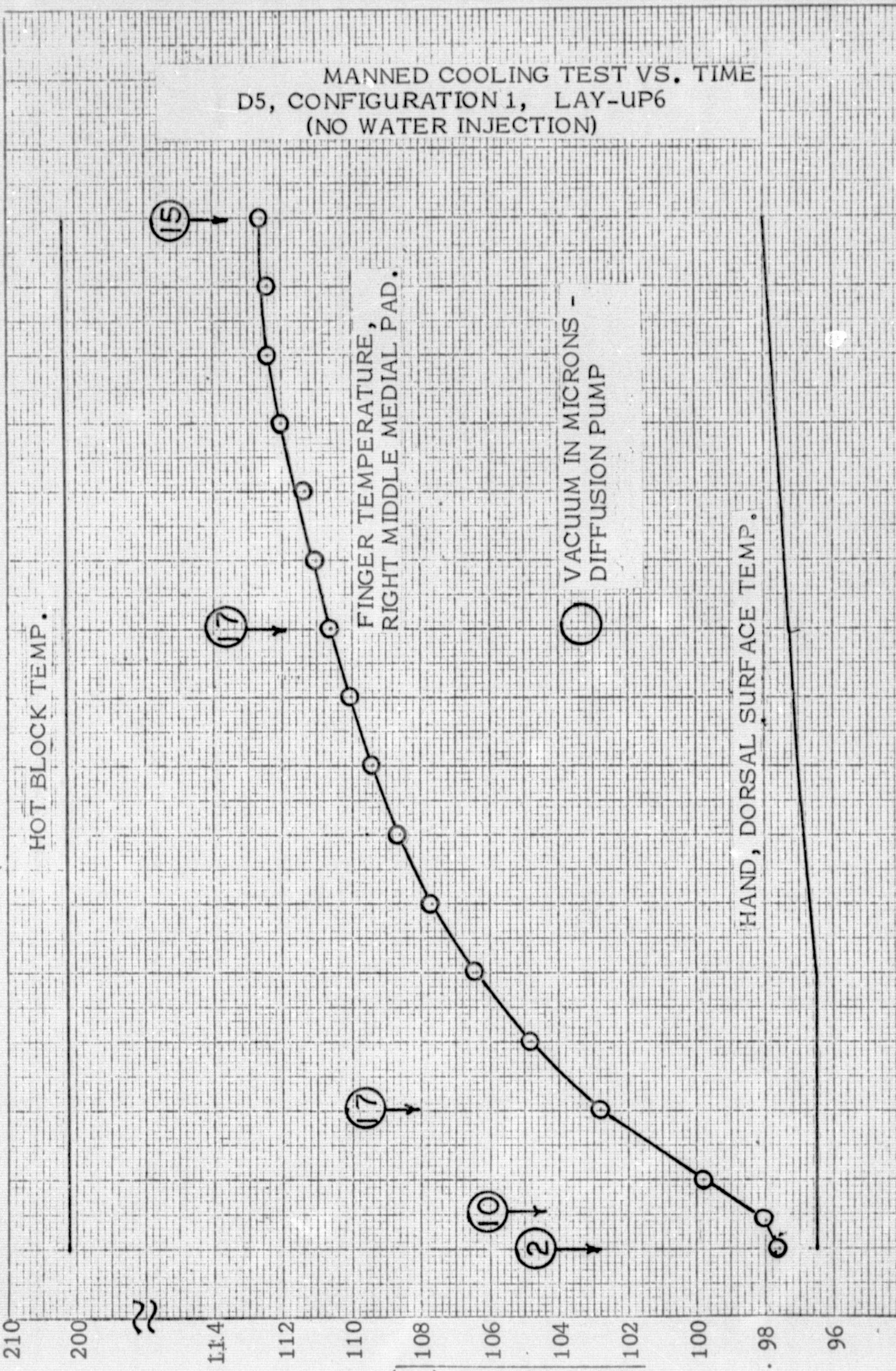


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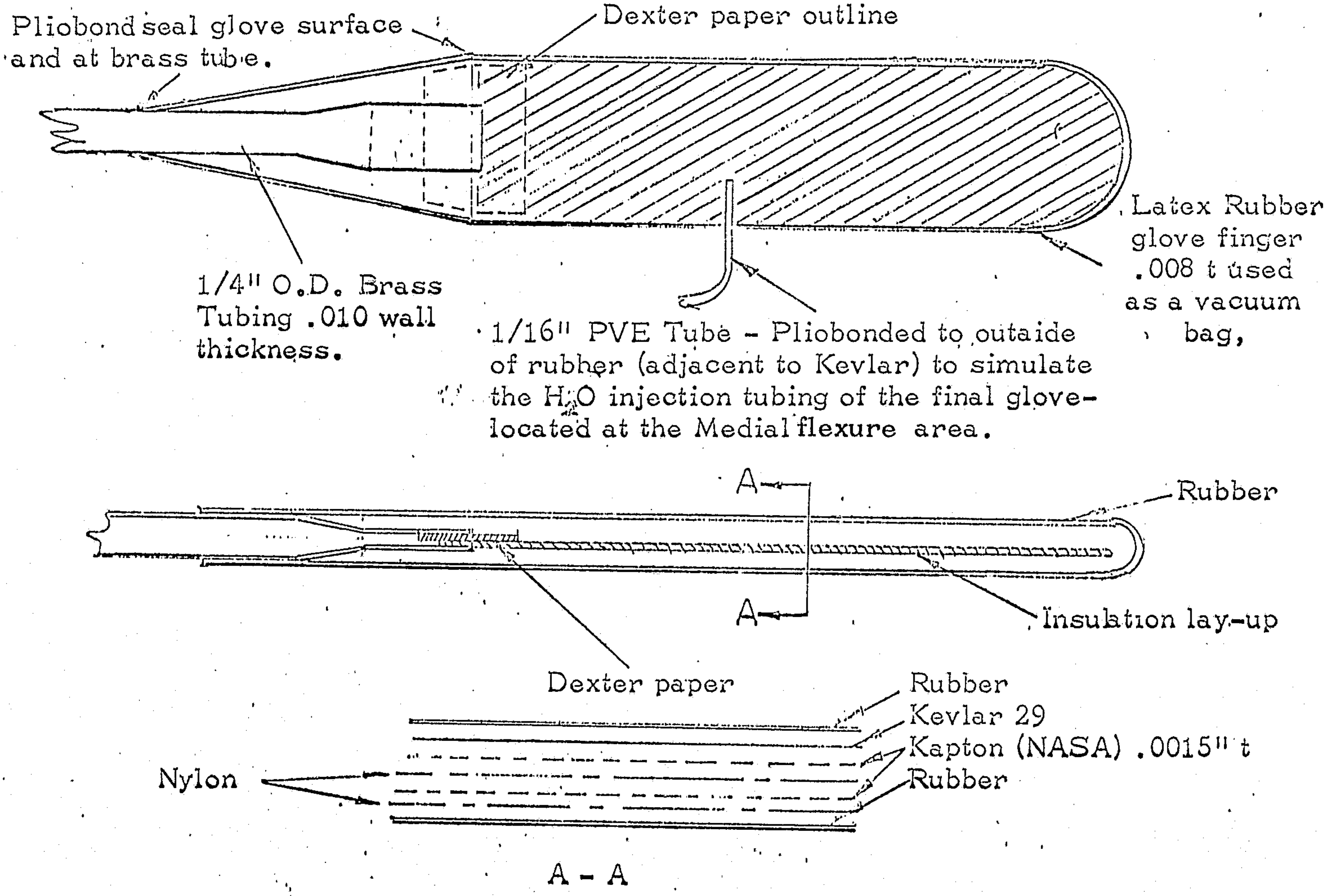
Figure 42

MP-2 INSULATION PATCH

Design for the cooled - heated prototype glove, but only for the middle finger. Patterned for F. Coss middle finger (right or left).



Note: Kapton silver side toward finger

Note: Run no. 6-34 to be initial run whith this insulation patch.

NOT TO SCALE

Figure 43

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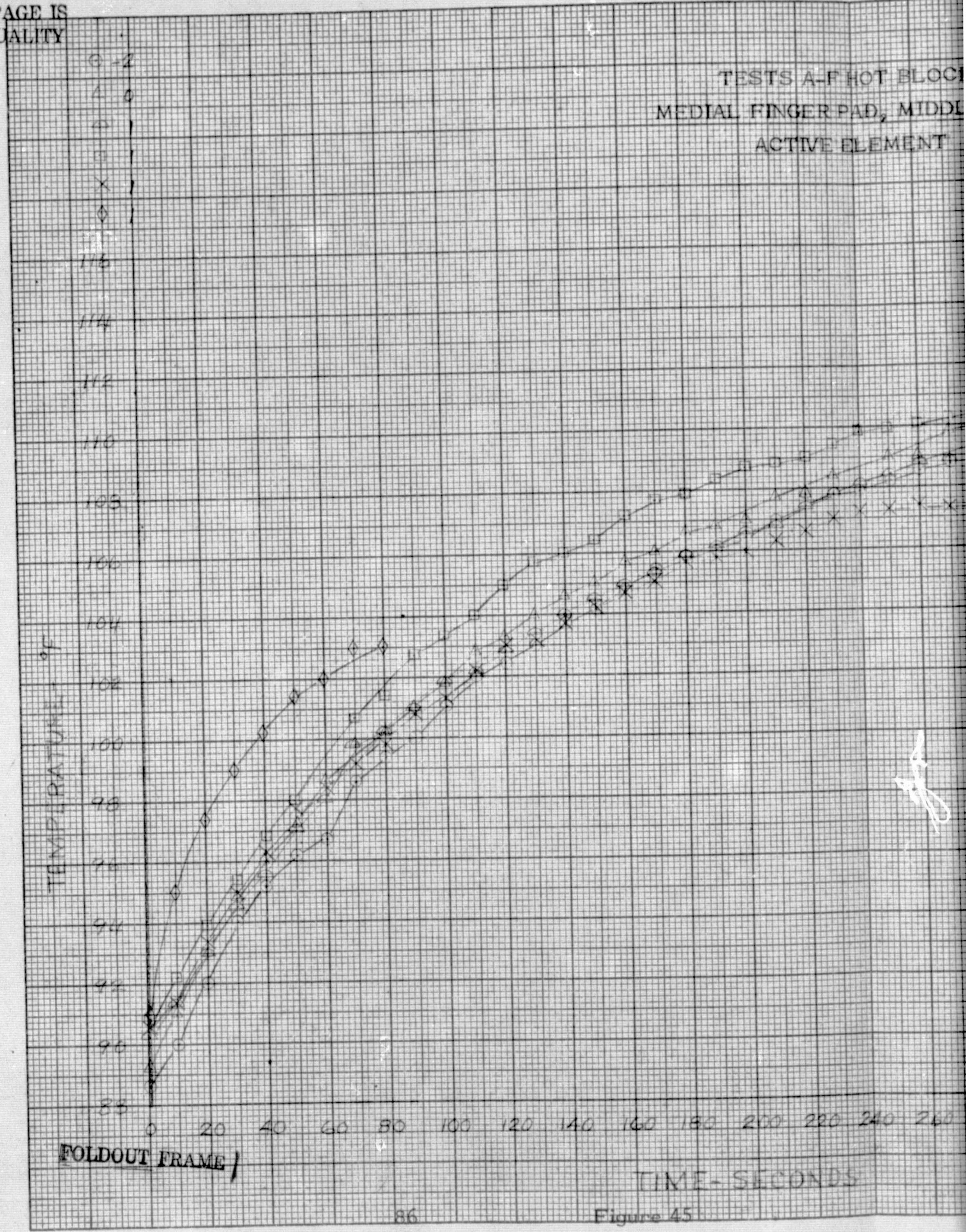

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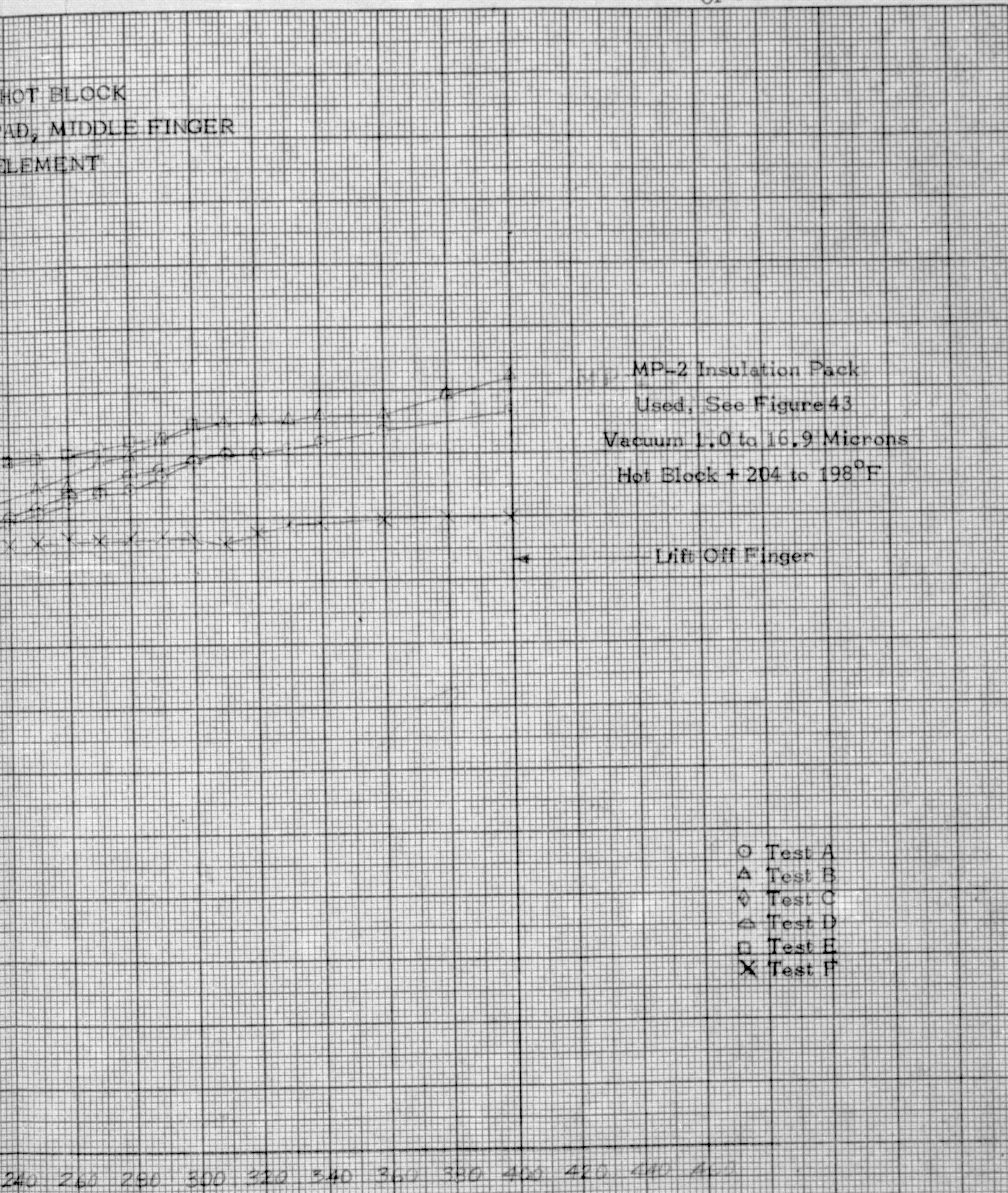
Figure 45



FOLDOUT FRAME 2

Figure 45

FINGER TEST PAD LAY-UP

TESTS A-K

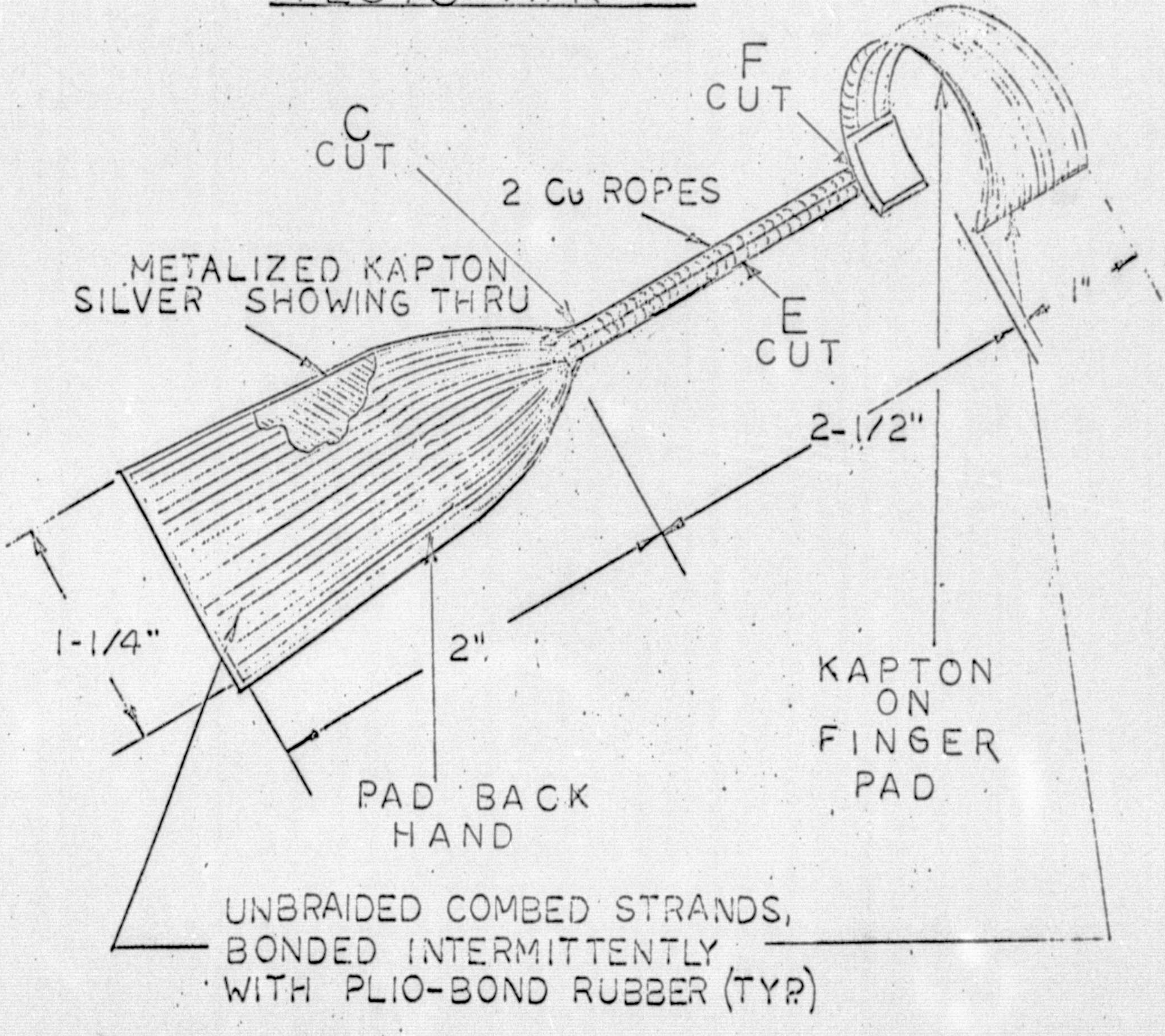


Figure 44

The total number of small (.002 in. diameter) wires is 665. The weight is .00067 lbs/inch or .119 grams/cm.

In the first test (A), using a hot body at +200°F, a Kapton covered two rope assembly (Figure 44), having approximately 2.2 in^2 area at the back of the hand, was used with the finger pad placed in the medial position of the middle finger. As shown in Figure 45, test (A), the finger temperatures reached 105.8°F at the end of 180 seconds and 111.3°F at 400 seconds. The vacuum level on the insulation pad varied from less than one to 7 microns. No significant pain was registered by the subject and the finger was normal post test. Test (B) was an identical test to test (A) except the back of the hand fan was insulated from the hand and therefore was essentially at room temperature. As shown in Figure 45, Test (B), the finger temperatures reached 106.6°F at 180 seconds and 111.4°F at 400 seconds. The vacuum level on the insulation pad was 1 to 12 micorns. Again, the post test finger reaction was normal.

In the succeeding tests, the copper conducting elements were progressively reduced in overall area and size. See Figure 44 for the cut points prior to tests (D) through (F). In test (F), Figure 45, the finger temperatures were 105.7°F at 180 seconds and 108.0° at 400 seconds. The vacuum level on the insulation pad was from 3 to 16.8 microns.

During this series, a hot body control test, (C), was run without a copper fan. The finger temperature was 103°F after

only 83 seconds. Due to the high rate of change coupled with the absolute temperature level the subject had to remove his finger from the hot plate at the 83 seconds point.

During this series all fingers were normal at the end of the tests. Data from test (F) above, showed that sufficient heat transfer could be accomplished using finger fans only. To increase the heat distribution, fans used in the following tests were fabricated in a band-like (fully circumscribing) configuration. One end was fixed (sewn to the comfort glove) and the other end overlapped approximately one centimeter. These band-like (active elements) copper fans were mounted on Kaptan with the silver side toward the finger. A second glove finger was sewn over the elements so as to contain and position the element and provide some restraining force without finger construction. This outer covering was not sewn in any way to the element. Two elements were used, one on the proximal and one on the medial pad of the middle finger. The weight of the copper plus the Kaptan for the proximal element was 2.14 grams and for the medial element was 2.05 grams.

Two tests were conducted as follows: The standard insulation pad MP-2, Figure 43 was used between the hot plate and the finger. The comfort glove, with the active elements, plus the rubber (membrane) glove were donned. At test the finger was placed on the insulation pad which was in turn placed on the hot plate (+200°F).

The medial active element only, weighing 2.05 grams, was used on Test VI. The data shows that at 180 seconds, the finger

temperature at the medial finger pad was only 105.4°F and after 400 seconds it was 107.3°F, Figure 46. The hot test block temperature ranged from +198.5°F to +202.5°F. The insulation pack vacuum varied from 1 to 17 microns.

Test X was conducted using the proximal and medial active elements described above. Unfortunately, the proximal temperature sensor fractured during the test, so only the medial finger pad temperature was recorded. As noted in Figure 46 at 180 seconds the finger temperature was 109.6°F and at 400 seconds it was 111.4°F. The hot test block temperature ranged from +208 to 185.5°F. The insulation pack vacuum varied from 10 to 15 microns.

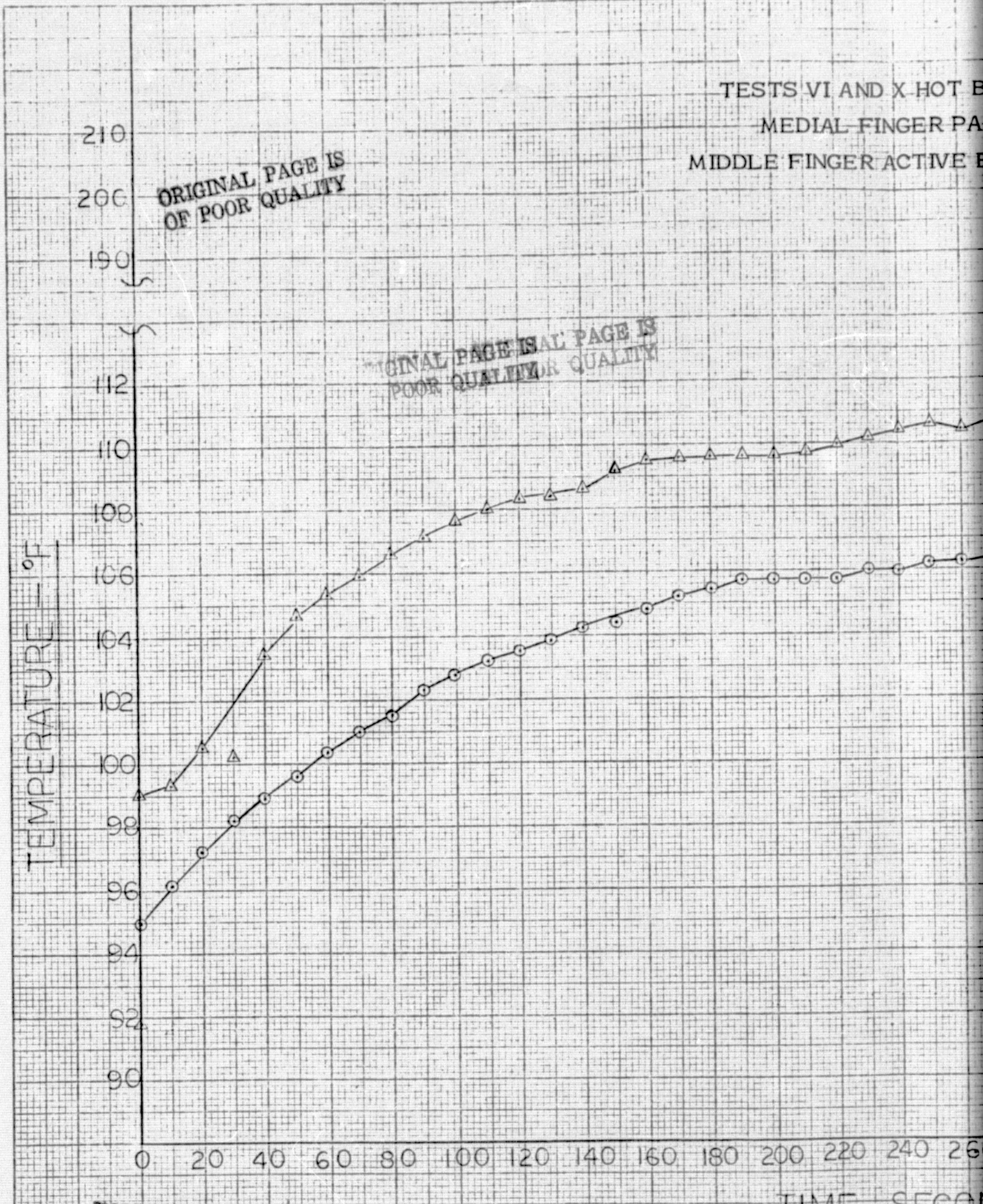
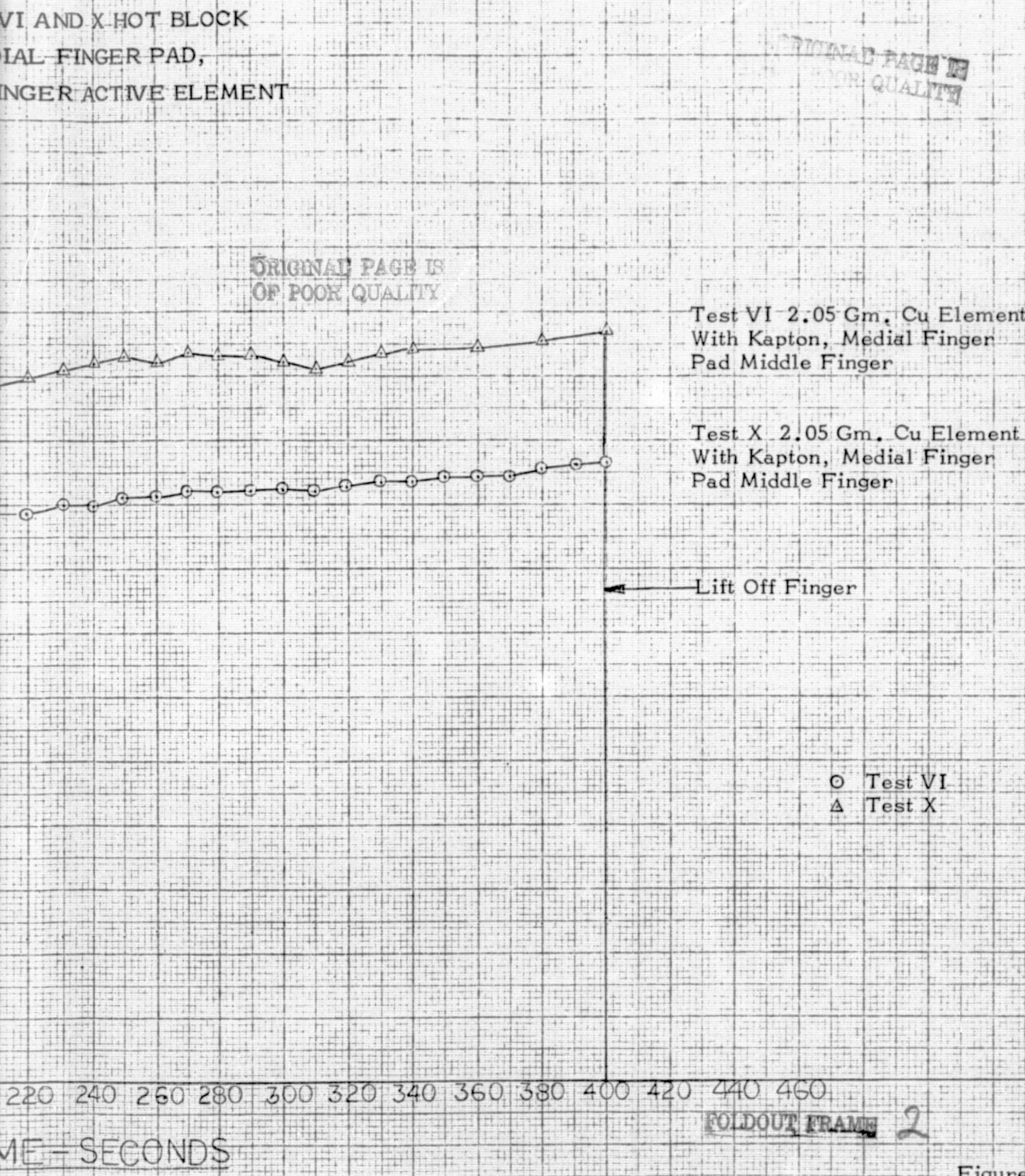

TESTS VI AND X HOT B
MEDIAL FINGER PA
MIDDLE FINGER ACTIVE E
TEMPERATURE — °F
210
200
190
112
110
108
106
104
102
100
98
96
94
92
90
0
20
40
60
80
100
120
140
160
180
200
220
240
26
TIME — SECO

Figure 46



FOLDOUT FRAME 2

Figure 46

GLOVE HEATING SYSTEM

Initial glove heating systems which were considered include the following:

1) Circulatory heating system using heat transfer fluids which would pick up heat from the upper arm or from a self-contained exothermic reaction, for the transport of heat to the hand.

2) Reverse ECGS condensational-heating using water as presented in the proposal.

3) Electrical heating using electrically conducting elastomers. Electrically conducting elastomers from the Dow Corning Corporation, and from Emerson and Cumings, Incorporated were reviewed.

A water circulatory heating system was analyzed, constructed and tested. The construction of the test model is shown in Figure 47. Heat was supplied to the fingers and palm by warm water (about 90°F) which was injected into a small volume space between two urethane layers surrounding the fingers and on the palm. The results of the initial tests were satisfactory, and appeared promising. A finger skin-temperature versus time graph is shown in Figure 48.

The tests were conducted as follows. Dry ice was used as the cold source. The heating system was worn on the finger as shown in Figure 47. The simulated, prototype-glove finger was then placed over this. As in the Insulation Tests, 91°F was chosen as the start and end temperature for the tests. When

HEATING SYSTEM TESTING DEVICE

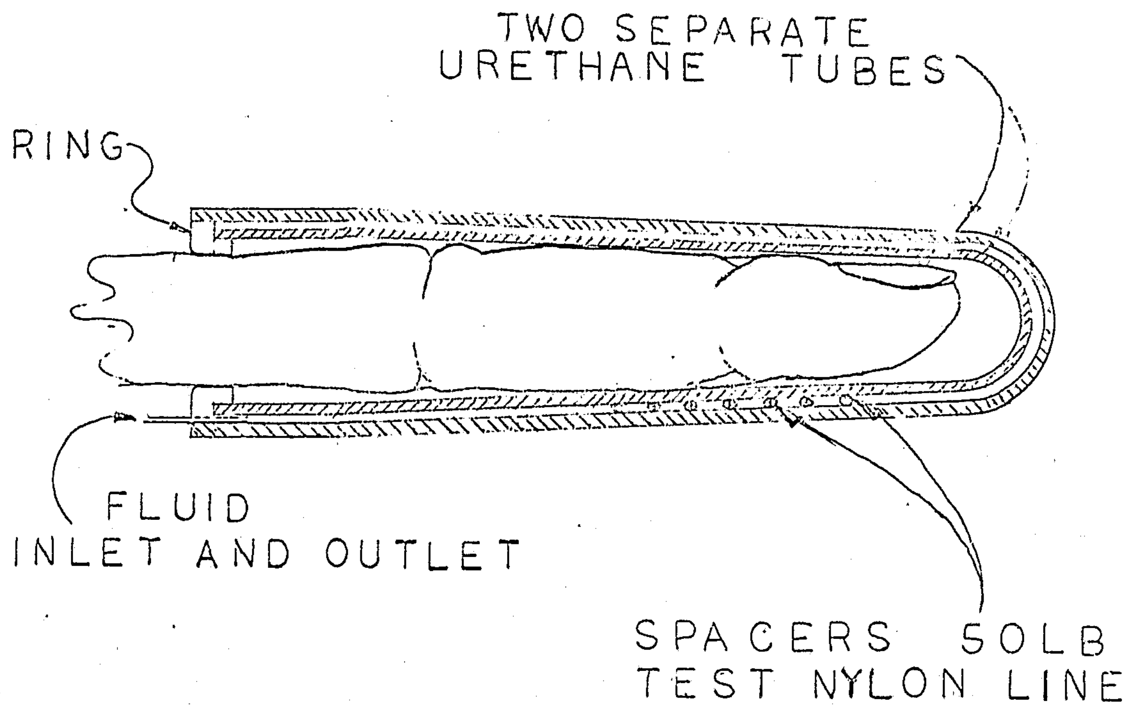
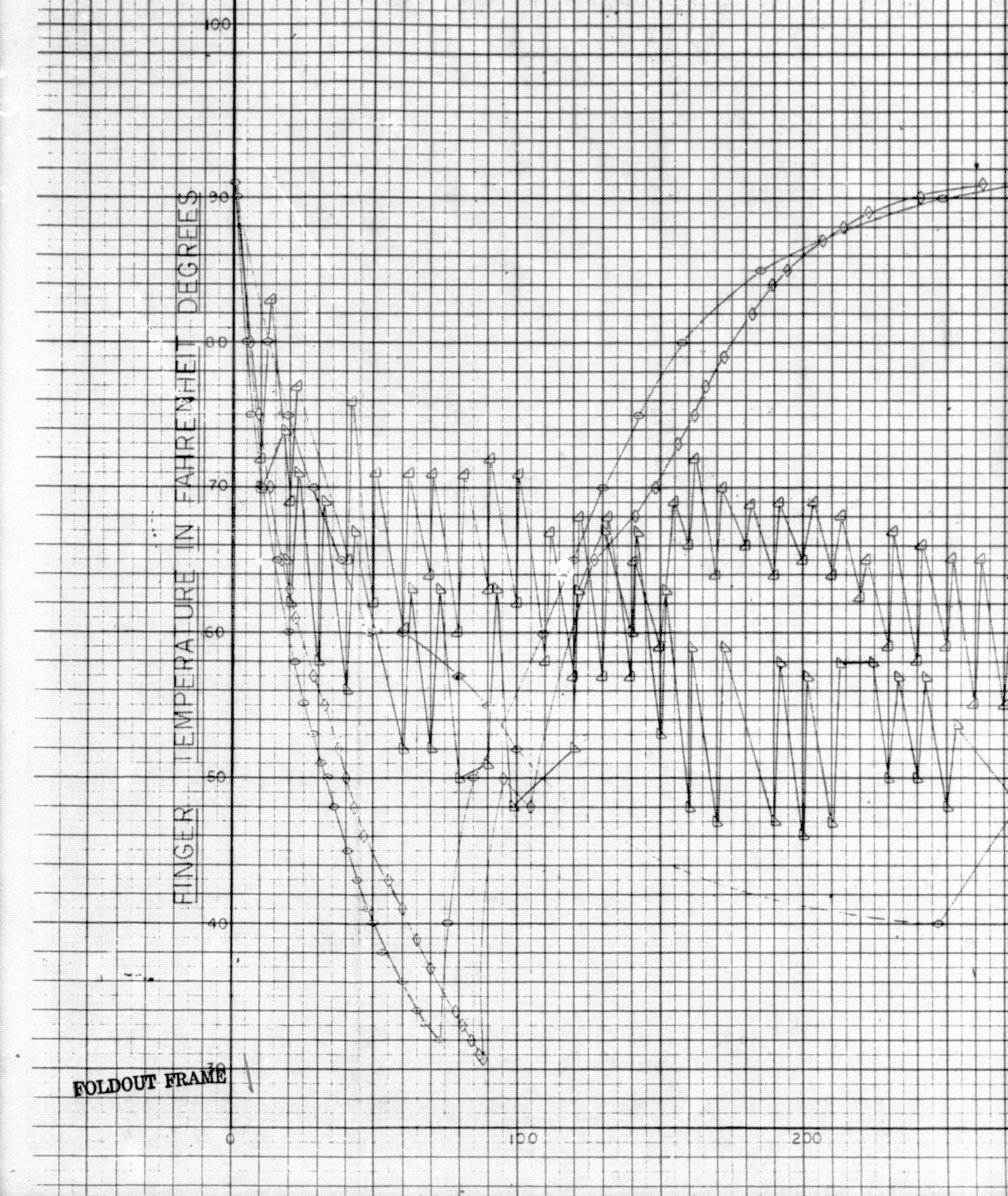
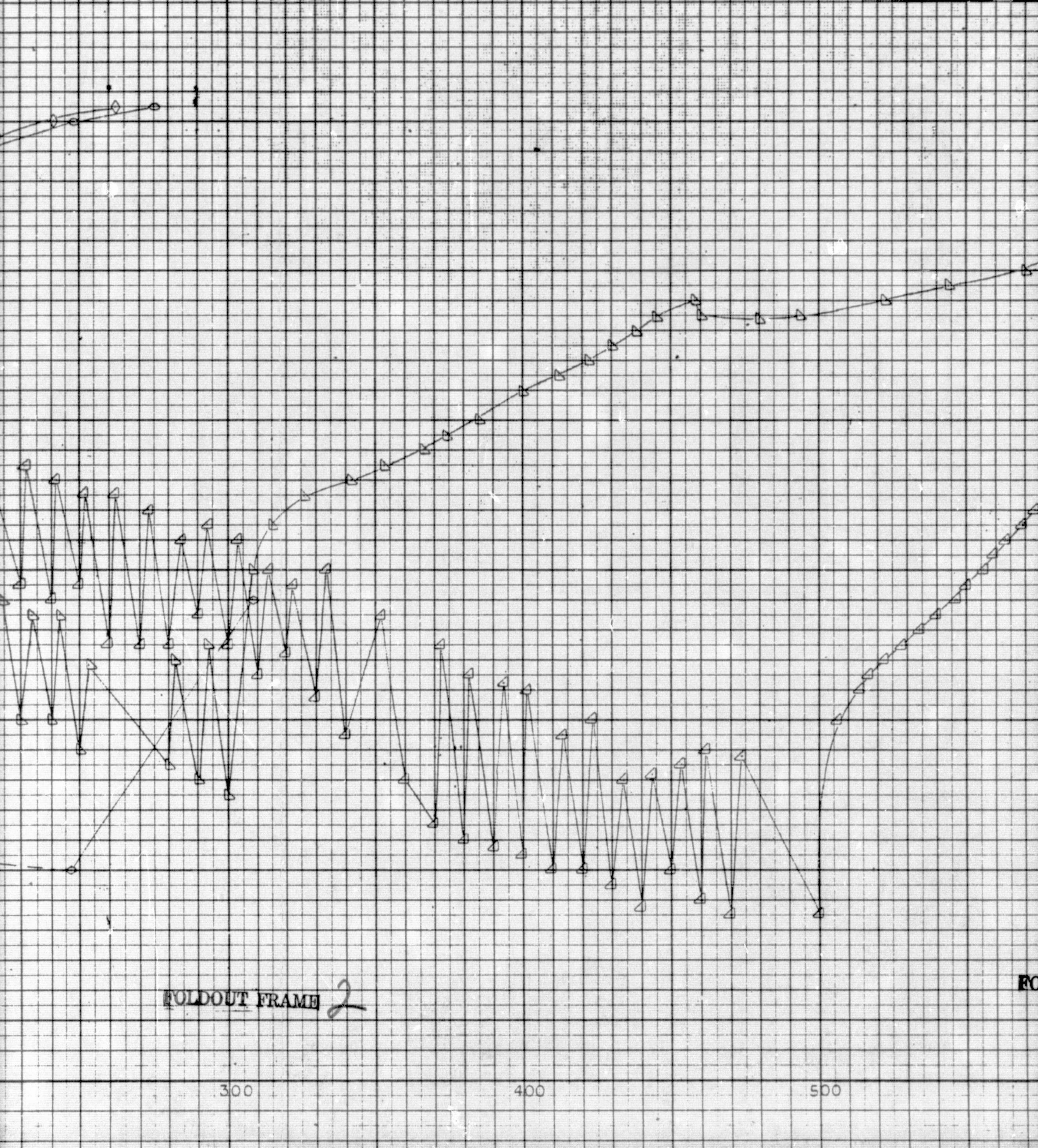


Figure 47



FINGER TEMPERATURE IN FAHRENHEIT DEGREES
100
90
80
70
60
50
40
30
0
100
200
FOLDOUT FRAME

HEATING SY



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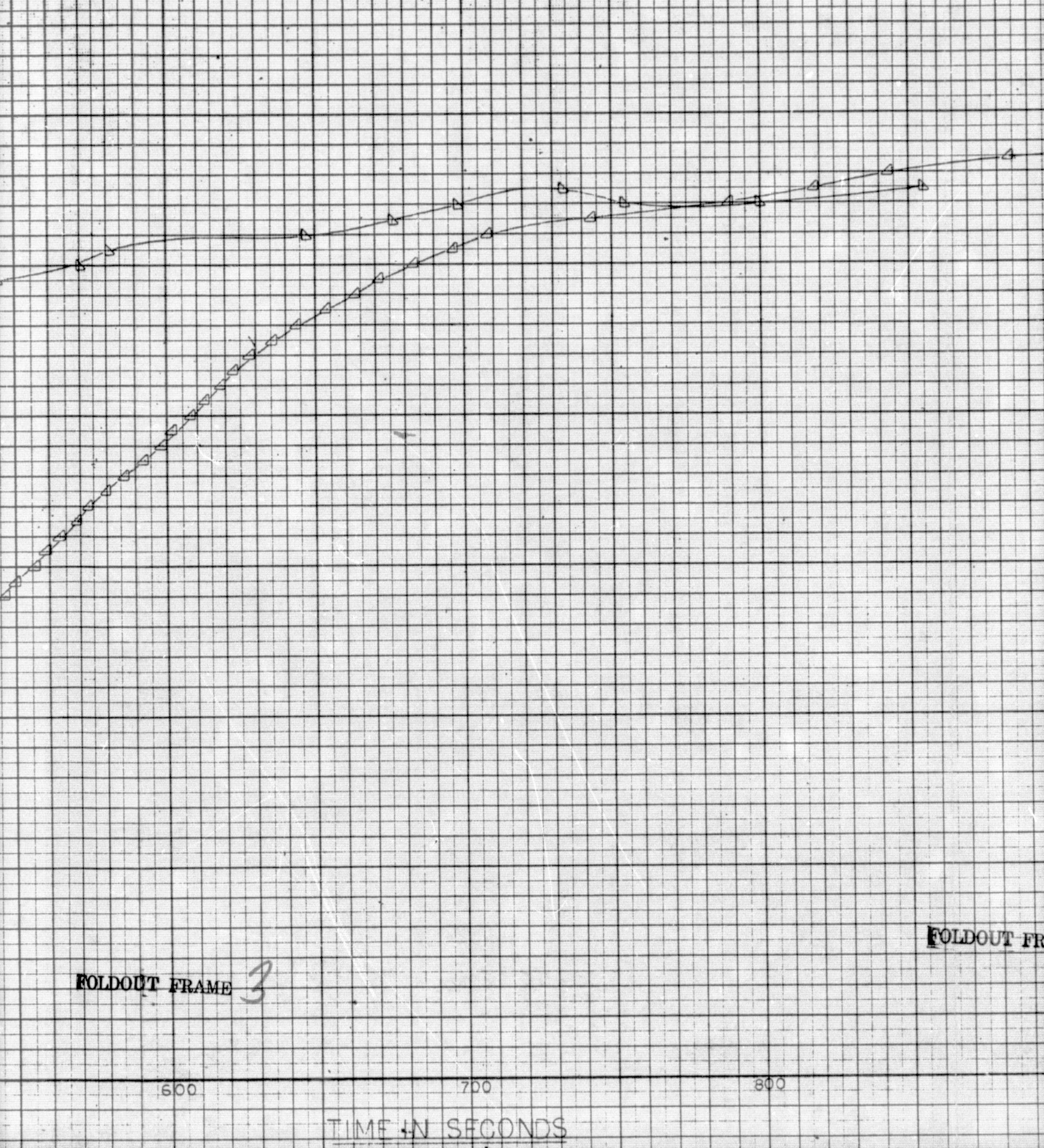
NG SYSTEM TEST DATA



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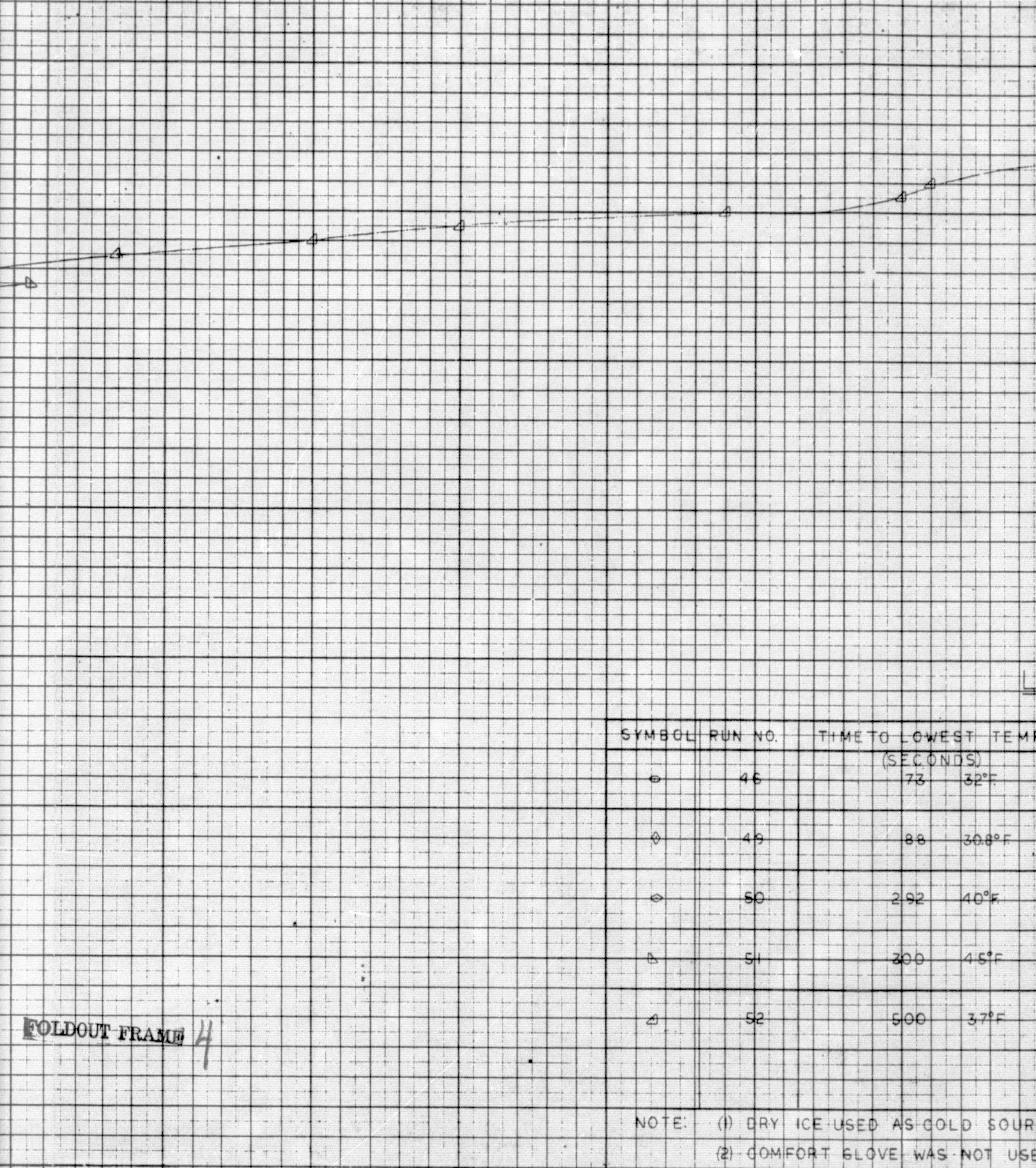


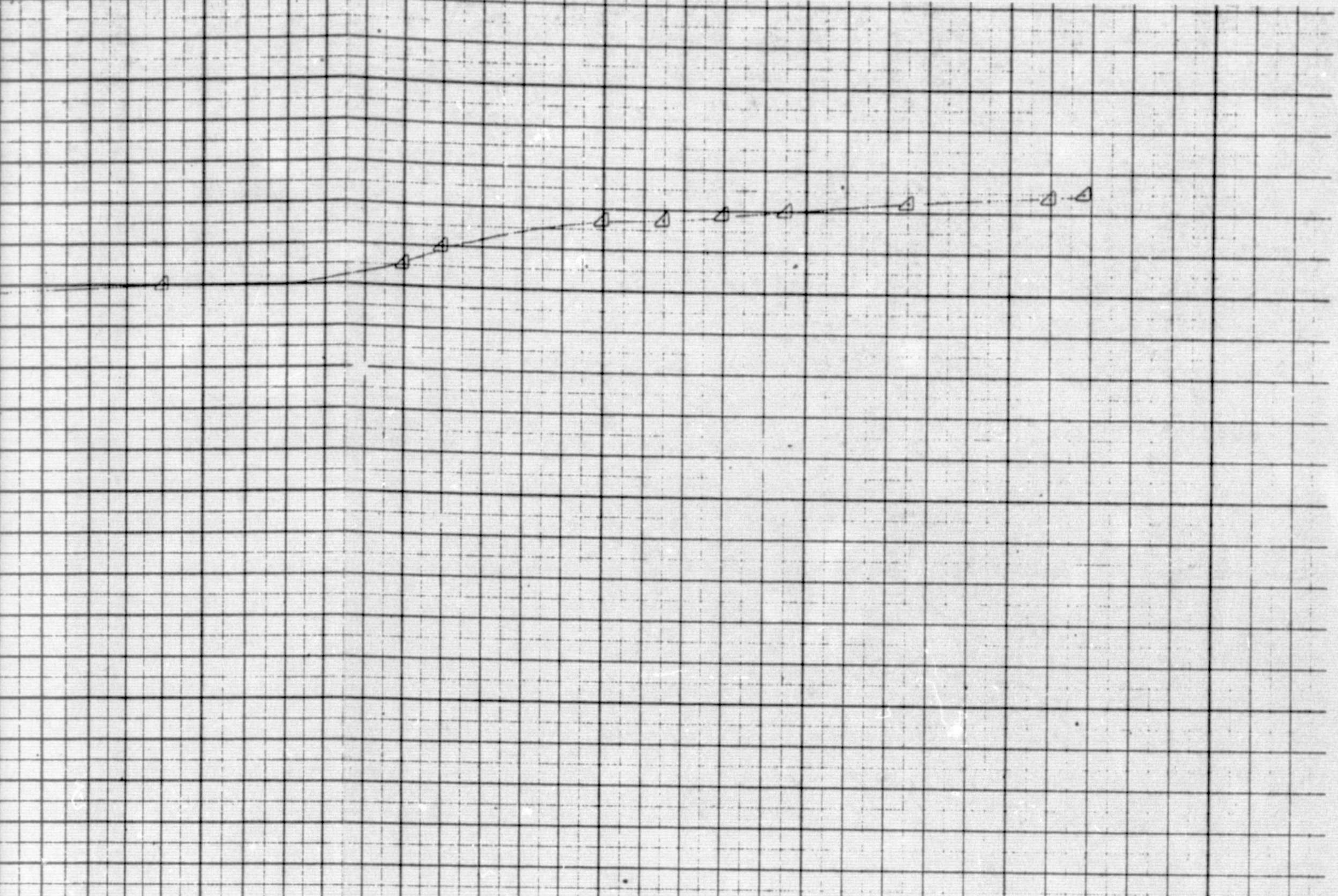
SYMBOL	RUN NO.	TIME TO LOWEST TEMP (SECONDS)	
⊖	46	73	32°F
◊	49	88	30.8°F
◊	50	292	40°F
◁	51	300	45°F
◁	52	500	37°F

NOTE: (1) DRY ICE USED AS COLD SOUR

(2) COMFORT GLOVE WAS NOT USE

FOLDOUT FRAME 4

FOLDOUT FRA



LEGEND

SYMBOL	RUN NO.	TIME TO LOWEST TEMP. (SECONDS)		FINGER USED	COMMENTS
⬭	46	73	32°F	G.F.S. RIGHT INDEX	DID NOT FLEX FINGERS
◇	49	88	30.8°F	SAME	DID NOT FLEX FINGERS
⬦	50	292	40°F	SAME	FLEXED FINGERS
△	51	300	45°F	SAME	SAME
◁	52	500	37°F	SAME	SAME

NOTE: (1) DRY ICE USED AS COLD SOURCE FOR ALL RUNS.
(2) COMFORT GLOVE WAS NOT USED IN ANY RUN

1100 1200 1300

FOLDOUT FRAME

FIGURE 48

this temperature was reached the finger was placed on the dry ice and the warm water injected. In the first two tests, run numbers 46, and 49 the finger was kept firmly on the dry ice without movement throught each test. This was done to determine the heating system's effectiveness in a static situation (i.e. warm water not circulating within the volume). As can be seen from the data the system's effectiveness was unsatisfactory under this condition. In runs 46, and 49 the skin-temperature dropped to 50°F in 33 seconds and 40 seconds, respectively. The cause of this is the fact that the water cannot warm the surface of the finger which presses against the dry ice (henceforth called the contact surface) because the water is squeezed to the sides of the finger. To correct for this, the last three tests (runs 50, 51, and 52) were conducted by lifting the finger off the dry ice slightly, and flexing it once every ten seconds (taking approximately two seconds to flex the finger and set it on the dry ice again). During these tests the finger-temperature rose and fell due to the flexing of the finger. When it was flexed, warm water circulated around the cold finger and warmed it. Results were very satisfactory as can be seen from the data. The finger was still able to be warmed to 58°F at 182 seconds in run 51, and to 69°F at 182 seconds in run 52. Run 50 is not very representative of the heating system's performance, and was conducted in a different manner than runs51 and 52. Because this was the first run in which the finger was flexed, problems arose in recording the finger temperatures. It was uncertain as to when and which temperatures to record as the temperatures moved up and down so quickly each time the finger was flexed. It was decided, therefore, to stop recording the data after 100 seconds, but to continue the experiment, flexing the finger only when the

temperature became uncomfortably cold. This was done in order to gain a qualitative assessment of the system's performance. It was arbitrarily decided to end the experiment after 290 seconds. However, as can be seen from the last data point the water was still able to heat the finger to 60°F after 308 seconds. The small amount of flexing of the finger produced quite a large change in the system performance.

Modifications were made to employ various spacing materials. The spacing material provided a small volume between the urethane layers of the heating system covering the flexor-surface of the finger. This volume allowed warm water to circulate, drawing warm water to the finger cold spots when it was pressed against a low temperature surface. Spacing material used included monofilament nylon line (1mm diameter), monofilament urethane bars 2mm by 2cm, Space Fabric from Uniroyal, various soft foam rubbers approximately 1mm to 3mm thick in the uncompressed state, and aluminized mylar 0.0508mm thick. These were used in various combinations.

One configuration using monofilament nylon line was able to meet the three minute requirement. It kept the skin temperature above 50°F for 209 seconds, and 196 seconds in two tests. Fifty degrees Fahrenheit is being taken as an arbitrary comfort threshold. The finger was pressed against the block slightly rocking at about 20 - 30 times a minute in a rythmic motion to create a minute pumping action causing the 90°F water heated by the warm parts of the finger to circulate to the cold contact points.

During these tests the finger never lost contact with the $-200^{\circ}F$ block.

Another configuration tested using foam rubber spacing material did not perform as well; it maintained finger skin temperature above $50^{\circ}F$ for only 139 seconds. The water was $110^{\circ}F$ and the finger was pressed against the block with the same rythmic motion.

Water Conductive Heating

Data obtained on the best manned test utilizing water as a heat transfer fluid is shown in Figure 49. The medial pad temperature never dropped below $50^{\circ}F$ during the 180 second test period. However, reference to the water temperature curve from 125 to 200 seconds indicates that performance was achieved by utilizing the latent heat of fusion for the 14 ml of distilled water. Thus for this approach to be successful on a continuous basis would require either minor changes in passive insulation, utilization of a different heat transfer fluid or perhaps a marked increase in water flow. Construction details are shown in Figure 50, Prototype Glove Finger-311.

The necessity to roll the finger to provide a pumping action was viewed by NASA with disfavor. Although other means to supply the pumping action could be engineered and the evaporative cooling system is compatible with the circulatory heating system it was decided to concentrate on another type of body heat supplied system.

MANNED TEST PROTOTYPE FINGER NUMBER 311

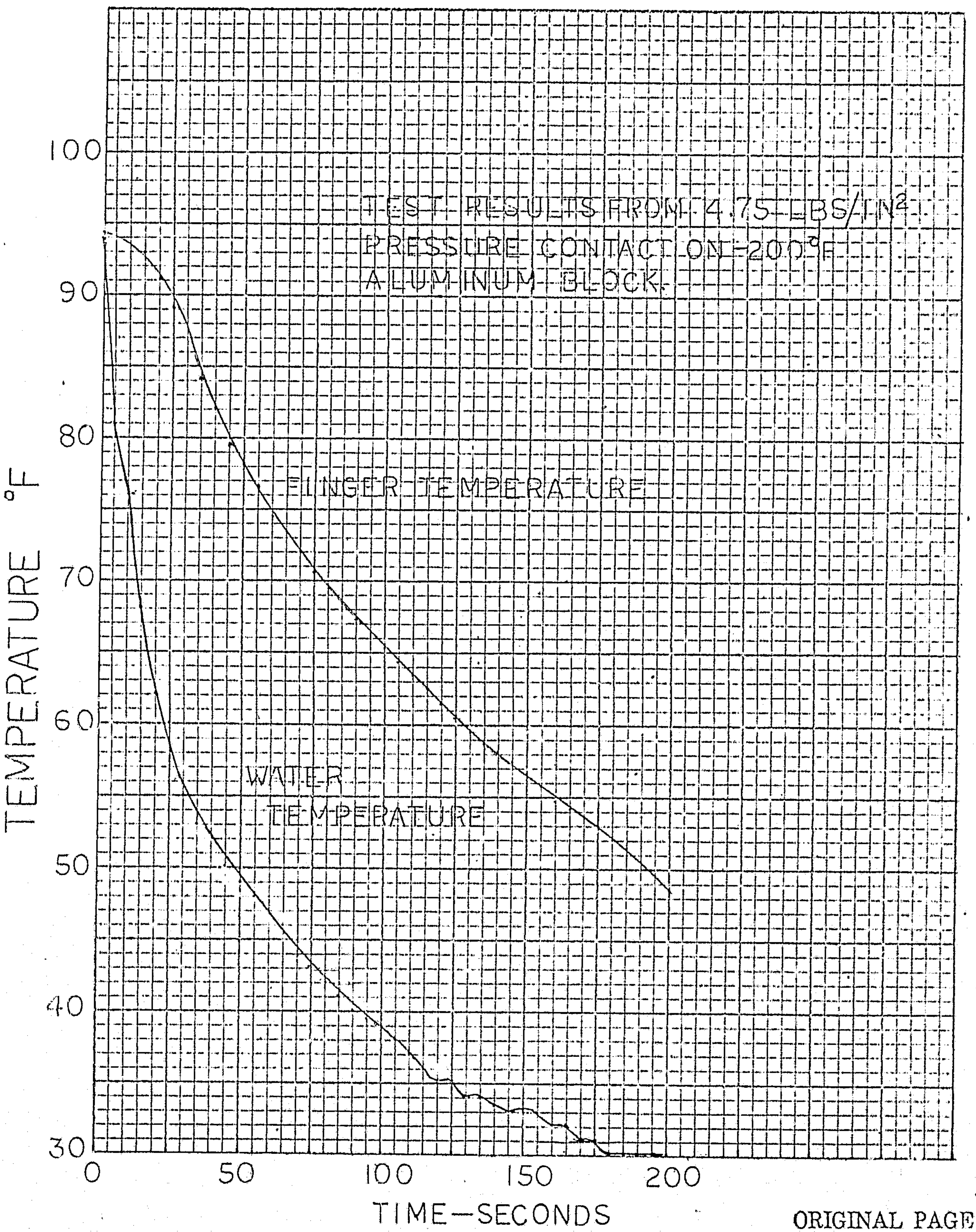


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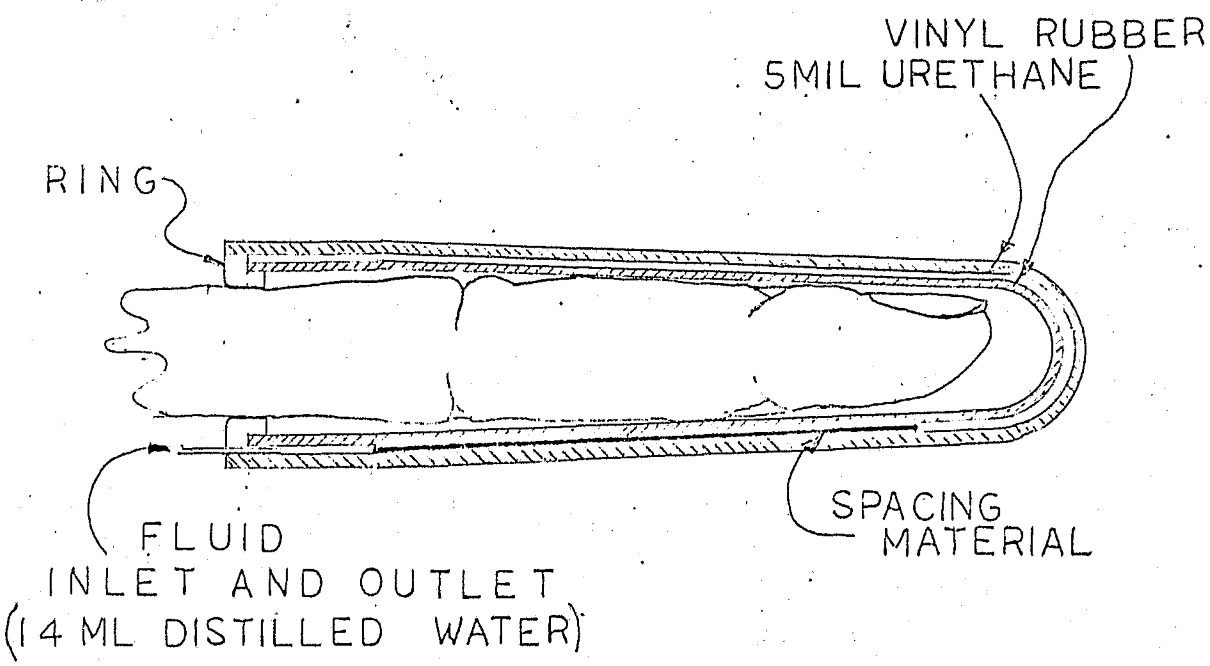
Figure 49

PROTOTYPE GLOVE FINGER - 311

NOTE: OUTER GLOVE FINGER 310 (KEVLAR, MYLAR, MYLAR KEVLAR) UTILIZED.



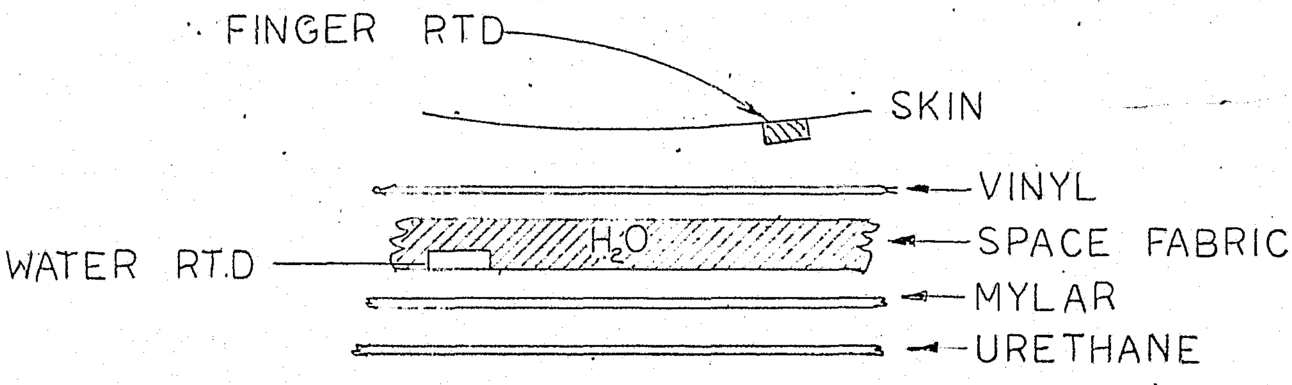


Figure 50

Finger Pad Thermal Output

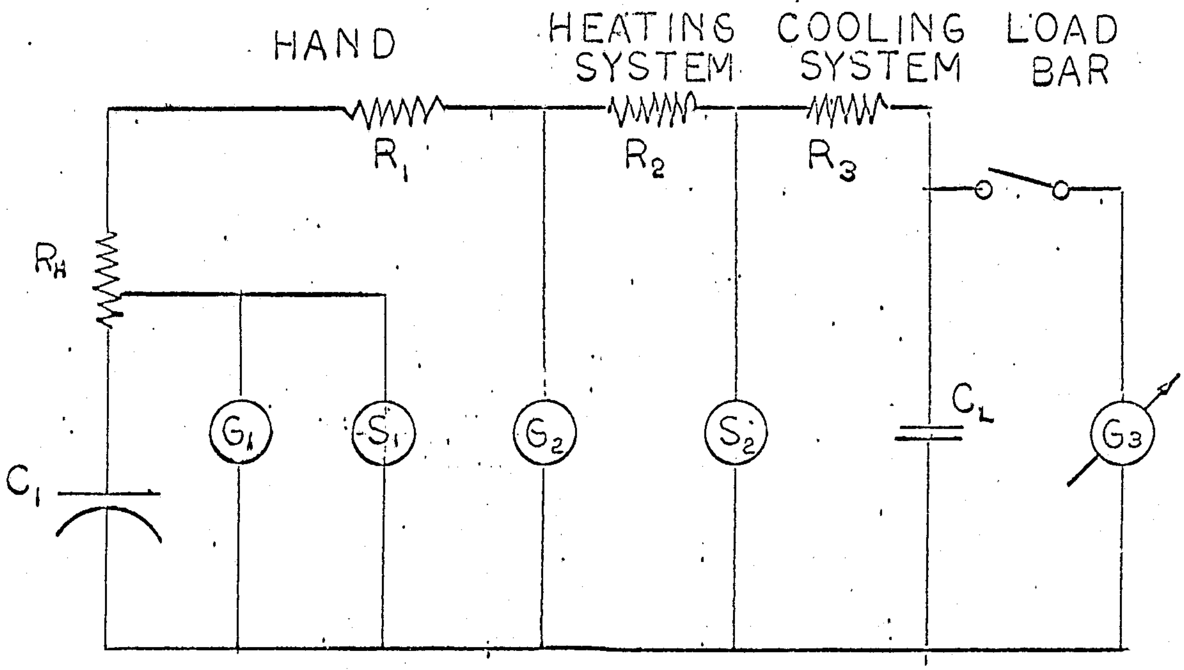
The finger pad thermal output was studied. As part of this, a simplified version of the glove thermal equivalent circuit is shown in Figure 51. Though simplified in form, this circuit allows a conceptualization of the various components (and their inter-relationships) necessary for glove heating (and cooling) system development.

The quantity of heat energy, Q, available as a function of both time and system operational conditions is quite important. For a completely passive glove design, such heat energy (represented by C_1 and G_1 in Figure 51) is the only source available. For ERA's active glove system the required heating system source (G2 in Figure 2) thermal output is the difference between hand output and load requirements.

Three test subjects and one control were evaluated for a preliminary indication of heat output per unit area of finger contact surface with no intervening insulation. This procedure was designed to 1) minimize the value of R1, 2) to give an indication of the maximum one exposure value of C1, and 3) to ascertain objective and subjective effects of forcing a bare finger directly onto a cold block (35°F).

A second four trial timed repetitive series utilizing one subject was run to 1) ascertain nominal values of finger pad thermal output while wearing a comfort glove, and 2) to see if a repetitive "immediate" thermal stress of 60°F (Δt = 95°F - 35°F) would cause activation. It did not.

EQUIVALENT CIRICUT, THERMAL GLOVE SYSTEM



DEFINITIONS:

C_1 -Hand bulk thermal storage (35° F to 100° F)
C_L - Bar bulk thermal storage or sink
G1 - Vascular thermal energy supplied
G2 - Active heating system
G3- Bar thermal generator or sink (200°F)
R1, R2, R3, - Thermal resistence of various composites
R_H - Distributed tissue thermal resistance
S_1 - Vascular heat removal
S_2 - Active cooling system (thermal sink)

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Figure 51

FIXTURE, FINGER HOLDER (TF-8)

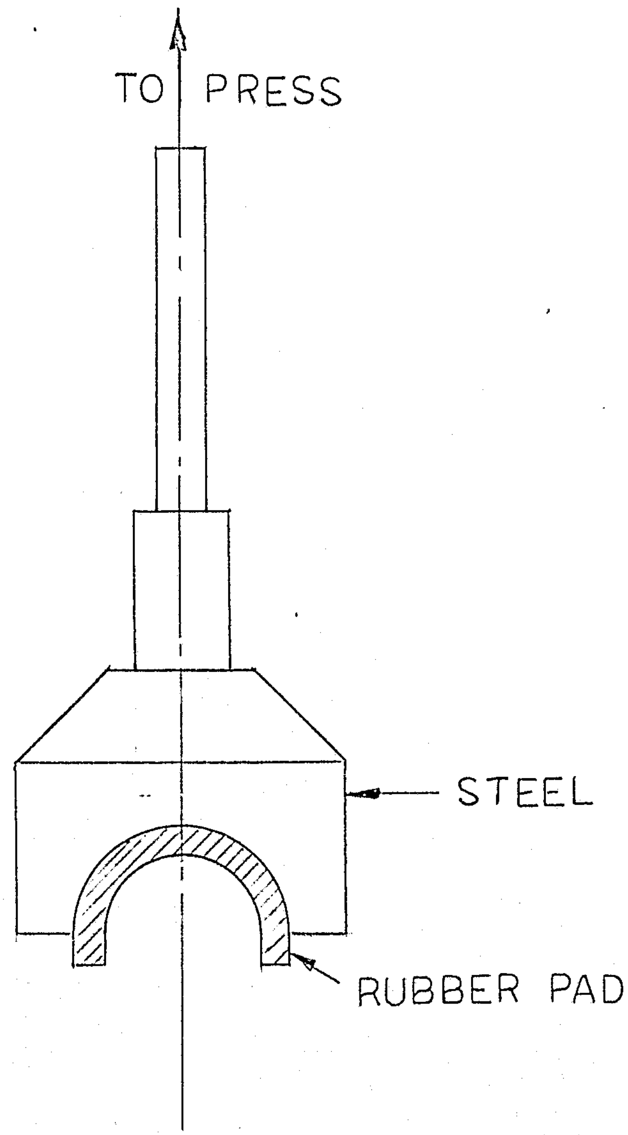


Figure 51a

Please refer to test fixture callouts (Figures 6, 7, and 10). The overall Block Diagram, Figure 6, was utilized with the following modifications. The spring was unscrewed from the Carrier Fixture (TF-2) as shown in Figure 10 and replaced with a U channel designed to fit over the aluminum block of the Heat Sink (TF-1, Figure 7). TF-2 was then inverted and placed on TF-1 with the sensor block up. TF-1 was not cooled and served only as a spacer for the press. A finger guide and pressure applicator (TF-8, Figure 51a) was inserted into the press.

Set up for a particular subject was made with the sensor block warmed to room temperature (70-80°F). The subject's middle finger, left hand, was inserted into the press such that the proximal pad was over the sensor block. The press was then activated and adjusted to the nominal force of 3.7 pounds (4.75 pounds per square inch pressure). A force range of 1.55 to 5.4 pounds was used for some tests in the series. After adjustment of the press the sensor block was cooled to approximately 32°F by momentarily touching it with the pre-cooled rod of TF-9, Figure 52. The block was then allowed to stabilize and warm to 35°F, at which time the subject inserted his finger into the holder and the press was actuated. Sensor block temperature and press force were then monitored as a function of time.

The rise in sensor block temperature as a result of thermal transfer from the finger is shown in Figure 53, Finger Sensor Block Temperature vs Contact Time. Slight differences between subjects may be seen, with a marked final decrement of almost 6 degrees for control subject S3. S3 is known to have severe peripheral vascular

COOLING SYSTEM, SENSOR BLOCK (TF-9)

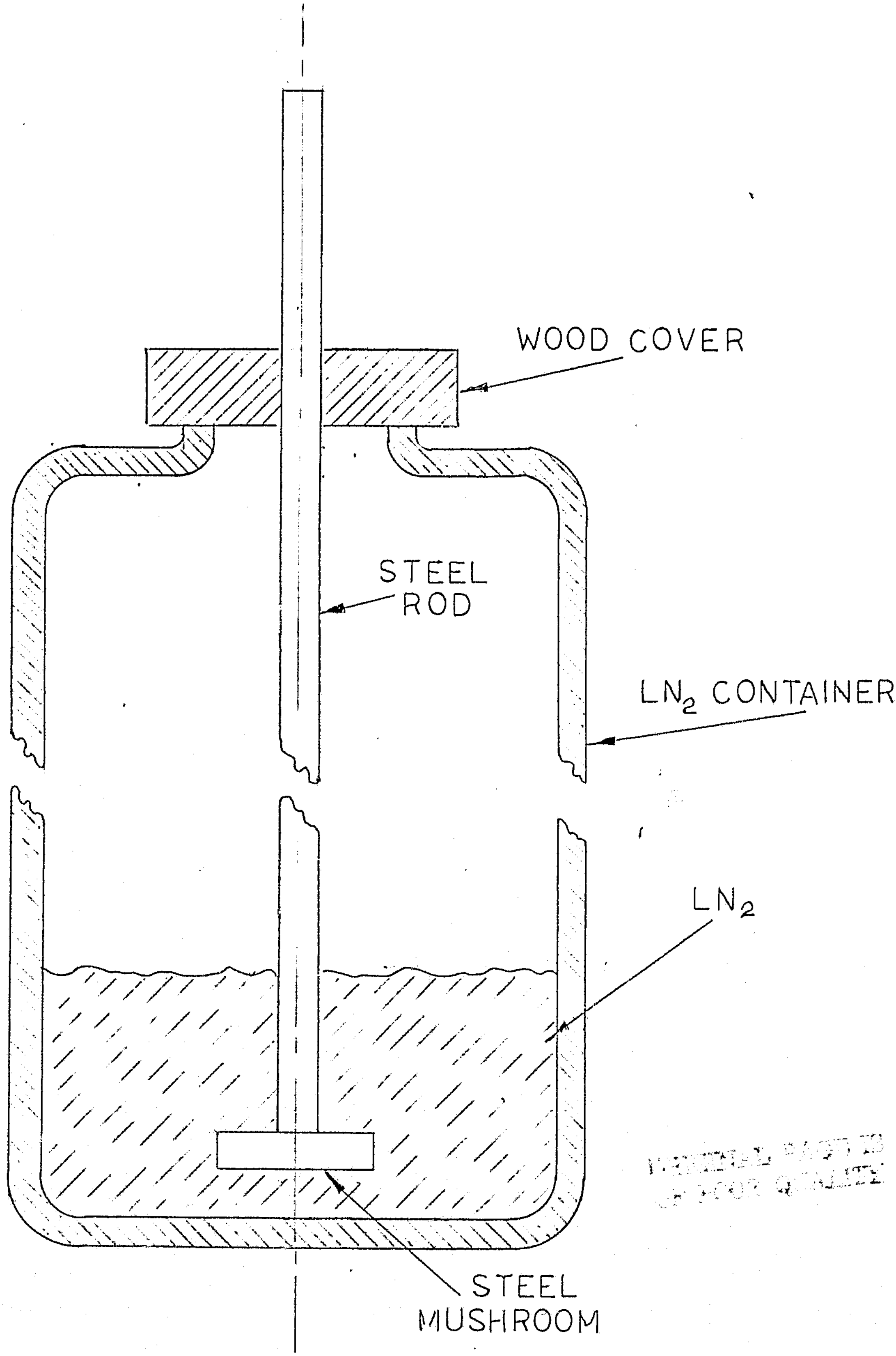
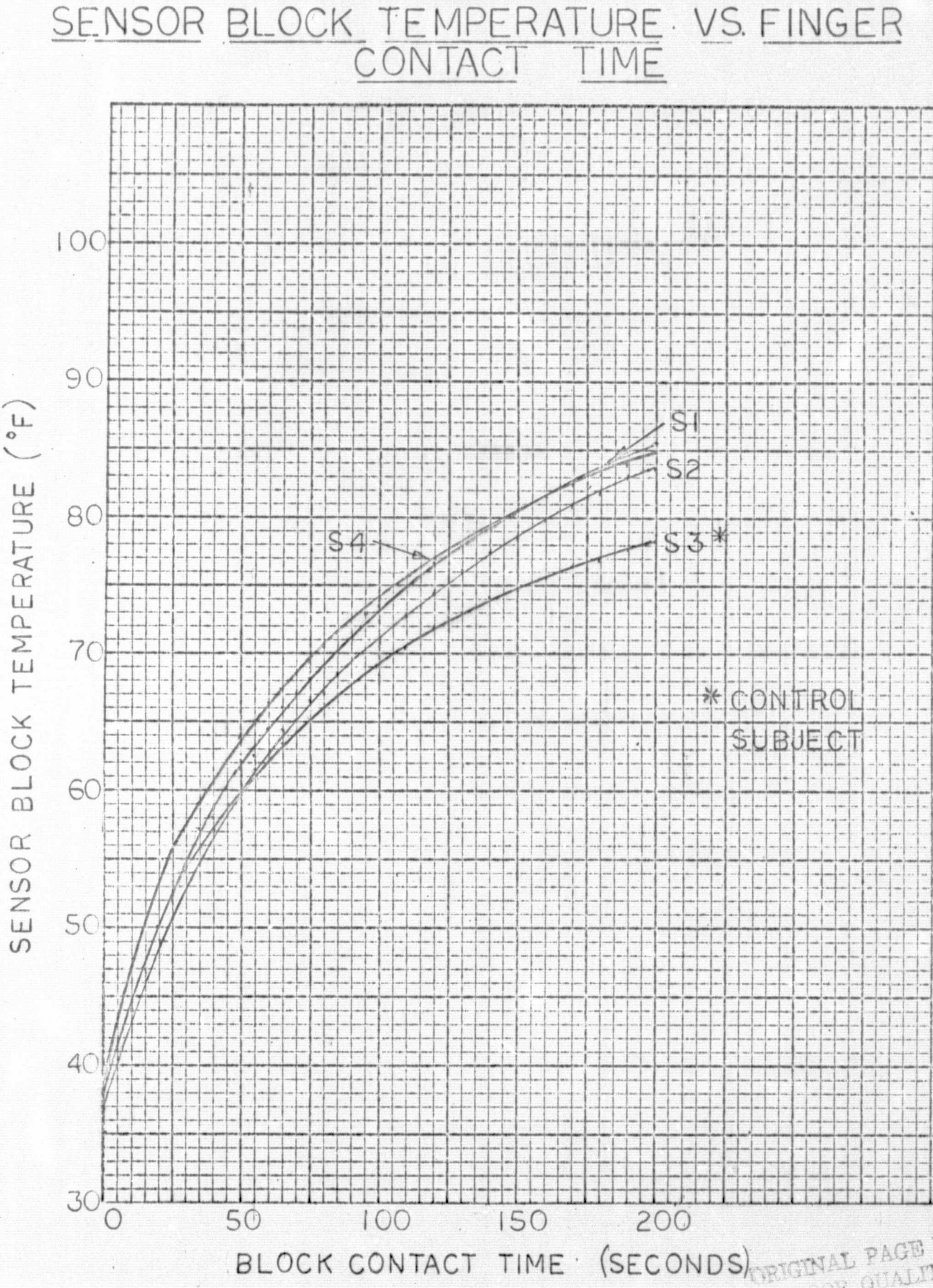


Figure 52



SENSOR BLOCK TEMPERATURE VS. FINGER CONTACT TIME
SENSOR BLOCK TEMPERATURE (°F)
BLOCK CONTACT TIME (SECONDS)
S1
S2
S3*
S4
* CONTROL SUBJECT
30
40
50
60
70
80
90
100
0
50
100
150
200

Figure 53

circulation problems and this health problem is quite evident when observing the test data.

Average finger heat loss in Btu's (for test subject 1, 2, and 4) is shown in Figure 54 relating finger thermal transfer vs time. This data indicates that approximately 0.190 Btu's were provided by the bare finger during a time interval of 180 seconds. Not shown on any of the curves is the fact that practically all subjects registered a drop in indicated force of approximately 0.7 pounds in the first 100 seconds. Thus tissue compression and blood volume changes are indicated as a result of the applied 4.75 pounds per square inch of compressive force. A slightly higher vascular component of heat transfer should thus be obtained in the more natural bar gripping mode. Later tests trimmed out this force reduction during experimental runs to a constant value to more closely represent a 12 pound pull.

Also shown on Figure 54 is the repetitive four trial average thermal transfer obtained for subject 4. Procedures were identical with those presented in above. The test and inter-trial periods were 200 seconds, the subject wore a comfort glove, and the left hand was warmed naturally by slipping on a black rubber space work glove (Schweickart's) for about 175 seconds between trials. Individual trial run data has not been presented, but all four runs were almost identical. This indicates that no activation was obtained from the repetitive 60°F stress and that the decreased thermal transfer (compared with bare finger data) is due primarily to the insulative properties of the comfort glove. "Discomfort" was not indicated by any of the test subjects as a result of the momentary exposure to the 35°F metal block.

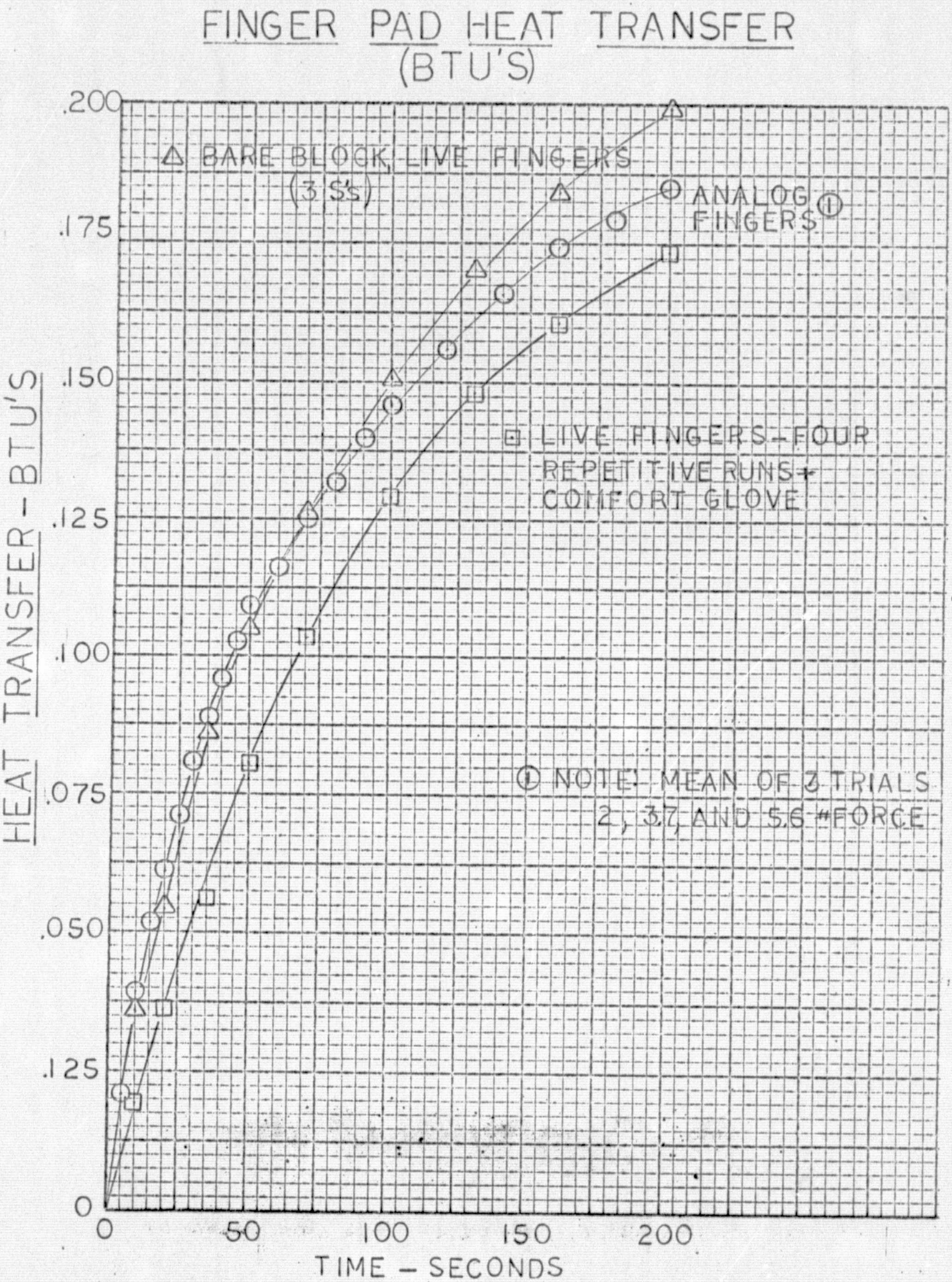

FINGER PAD HEAT TRANSFER
(BTU'S)
BARE BLOCK, LIVE FINGERS
(3 S's)
ANALOG FINGERS ①
LIVE FINGERS - FOUR REPETITIVE RUNS + COMFORT GLOVE
① NOTE: MEAN OF 3 TRIALS
2, 3.7, AND 5.6 #FORCE
HEAT TRANSFER - BTU'S
.200
.175
.150
.125
.100
.075
.050
.125
0
0
50
100
150
200
TIME - SECONDS

Figure 54

Initial values for C1, R_H, and G1 (Figure 51) were calculated by assuming a conservative value for Q (at 180 seconds) of 0.150 Btu.

Theory plus the generally exponential form of the finger pad thermal transfer data indicated that the majority of hand energy available for a 180 second test period will come from bulk thermal storage of the tissues. To check this hypothesis a test series was established utilizing Ol' Virginia Brand Frankfurters as analogs.

A number of weiners were placed in a pan of water maintained at a temperature between 95 and 100°F for a period of at least 30 minutes prior to a test. Test forces of 2, 3.7, and 5.4 pounds (2.6, 4.75, and 7 pounds per squre inch) were utilized. A surprisingly small difference in heat transfer as a function of pressure was noted, with a maximum variation in sensor block temperature of 1°F at 200 seconds. This value corresponds to a differential thermal transfer of only 0.0041 Btu's over a 200 second period. Cold flows of the weiners (as indicated by a drop in applied force) were pressure sensitive however. Approximate cold flow values for the three forces utilized were 18, 21.6, and 26%, respectively. The value of 21.6% at 4.75 pounds per square inch pressure was only slightly higher than the nominal 18.9% observed for live subjects. This indicates that the "weiner" analog could be more extensively used in difficult lab tests where a vacuum environment is otherwise required in a manned chamber. An average curve of thermal transfer for the "analog finger" is shown on Figure 54 to facilitate comparisons. For example no difference is apparent between the analog and live finger below 50 seconds. The difference at 200 seconds is only 0.015 Btu's, which is approximately one half of the difference noted for S4 with a bare finger, or equal to the incremental effects

a comfort glove. The slope, however, of the analog finger thermal transfer curve begins to deviate significantly at about 150 seconds. This slope of the analog presumably differs from the actual finger because of deep core blood circulation which would affect the heat transfer rate at the longer time periods.

Condensation and Electrical Heating

The possible use of reverse ECGS Condensational-heating (using water) was dropped early in the program since the required enclosure of the condensation unit would be bulky when added to the external evaporative cooling system.

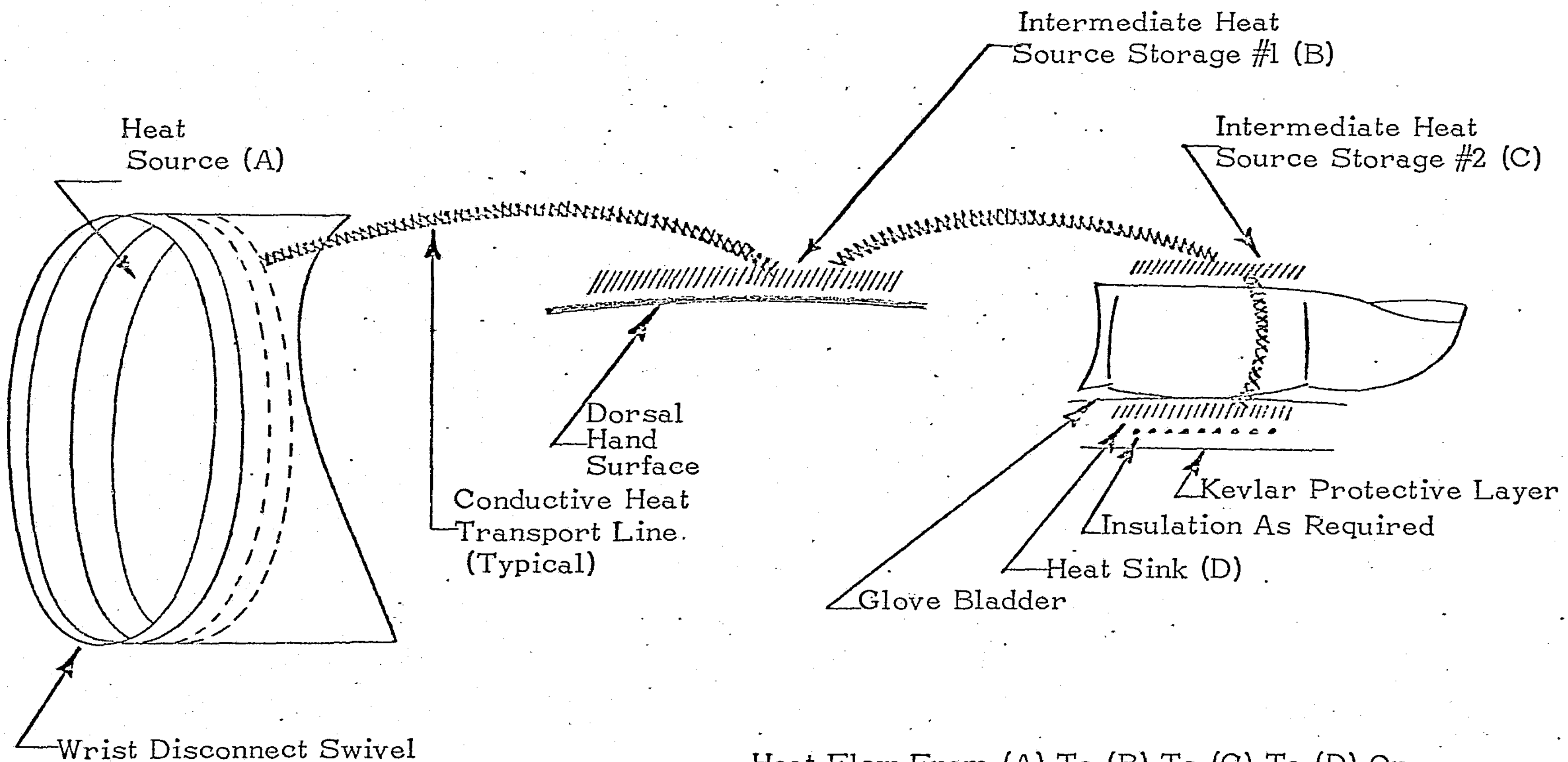
Electrical heating was also dropped by agreement with NASA that it should not be used on this program. However, the use of conductive elastomer, although still requiring a power supply with the attendant problems is considered a more viable design than the use of the standard resistance wires.

Heating System - Manned Tests

The water circulatory system early successes indicated that the use of heat conducted from a warmer part of the body to the finger pad areas was definitely a good idea. Therefore, tests were run to evaluate the concept of actively utilizing heat naturally stored within the glove and conducting it to finger areas via thermal conductors. A block diagram of this concept is shown in Figure 55.

A survey was made of candidate materials for heat transfer. All

SCHEMATIC GLOVE HEATING CONCEPT



Heat Flow From (A) To (B) To (C) To (D) Or Combinations Of Steps From (A) To (D).

Arm And/Or Suit Vent Flow Will Provide Heat To (A) By A High Surface Area Foil Collector Attached Thereto.

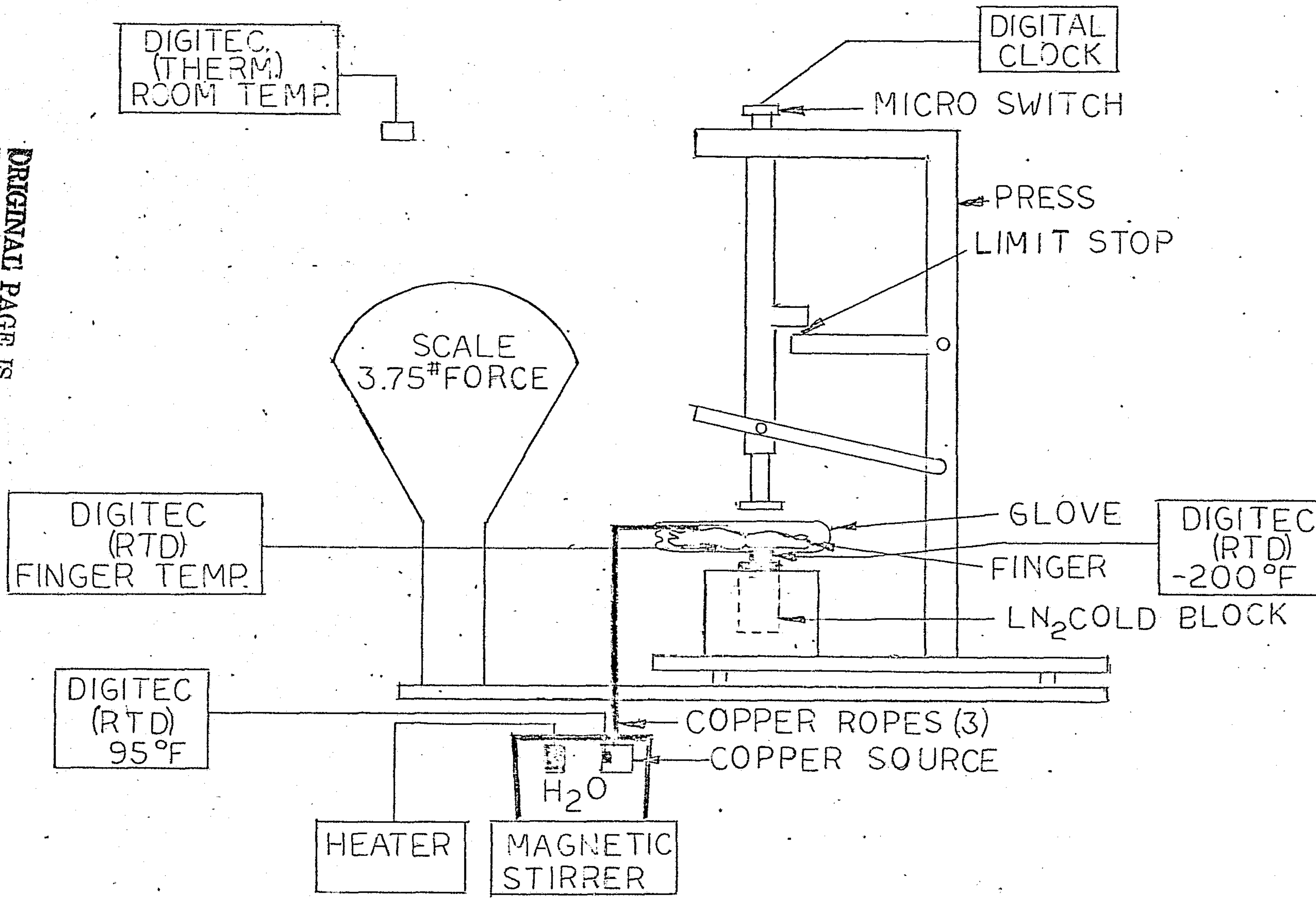
Figure 55

materials have significantly poorer coefficients of heat transfer than silver and copper. Copper, with a thermal conductivity of 0.918 (Cal cm/cm^2 - Sec - $^{\circ}$C) is second only to silver (1.006). In addition, copper has a 17.2% weight advantage over silver as well as a 38.7% thermal storage advantage. Silver surface finishes are preferred, however. Thus an optimum materials choice for conductive elements within the glove appeared to be copper with an appropriate silver finish. Plain copper multi-strand copper rope was used for the thermal conductivity tests (and in the final glove).

The test equipment utilized and its general set-up are shown in Figure 56, Manned Test Set-up - Copper Fan Source. Three copper ropes (7x65x44) having a length approximating the finger - disconnect ring distance were run to the middle finger of the subject's left hand. The ends of the copper ropes were simply fanned out and wrapped around the proximal or medial pads.

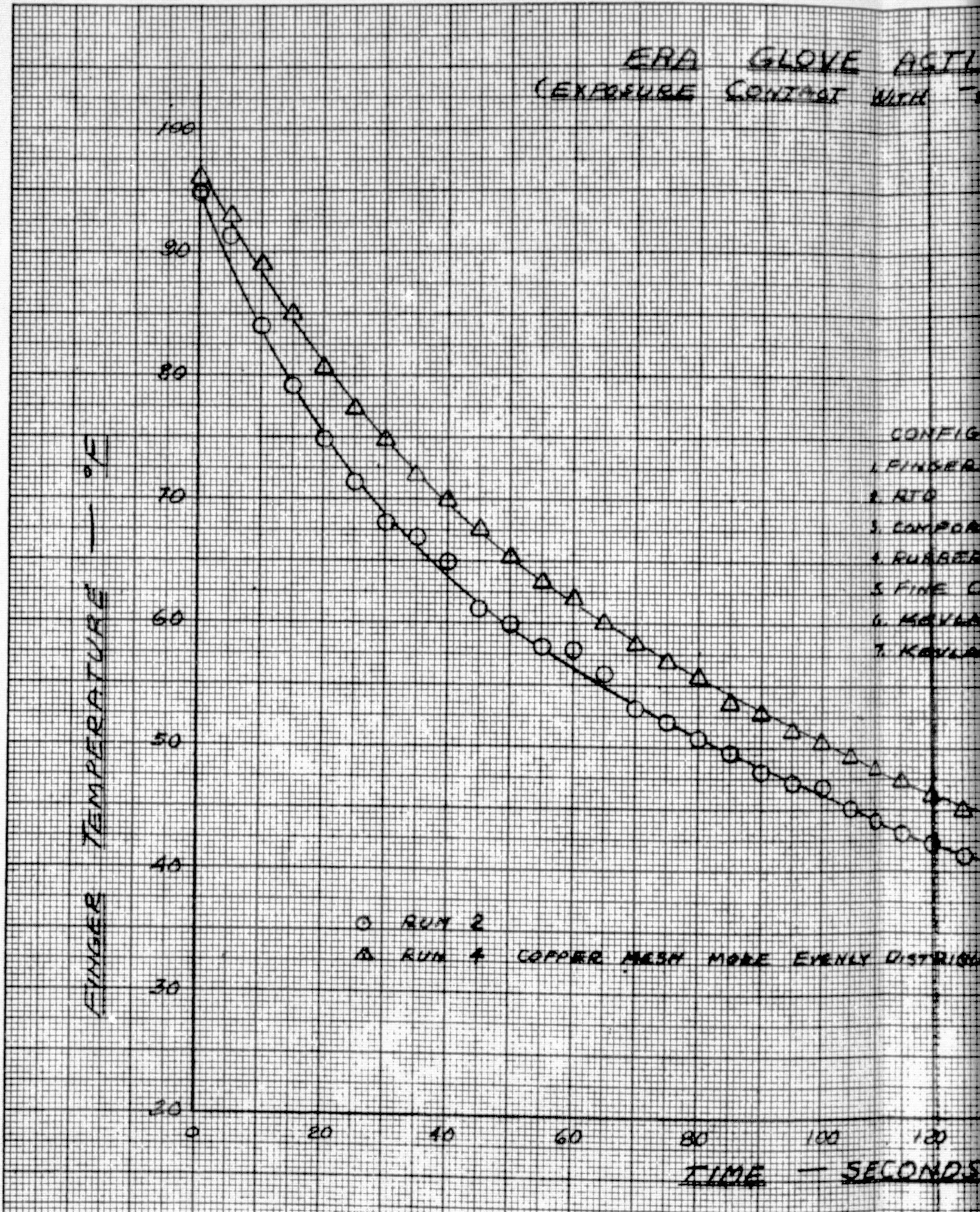
Various test conditions and insulation layers were initially experimented with to generally test the concept for feasibility. This information is called out on each of the three (3) graphs of finger temperature v's time, Figures 57,58 and 59.

Figure 57 shows the effect of mesh (or fan) evenness in controlling heat distribution. A simple "combing" of the free ends raised the average finger temperature 5°F. Figure 57 presents data concerned with the comparative efficacy of the thermal elements involved. Run 4 duplicated Run 2 (Figure 57) and provided essentially the same thermal protection as well as proved



MANNED TEST SET-UP — COPPER FAN SOURCE

Figure 56



FOLDOUT FRAME 1

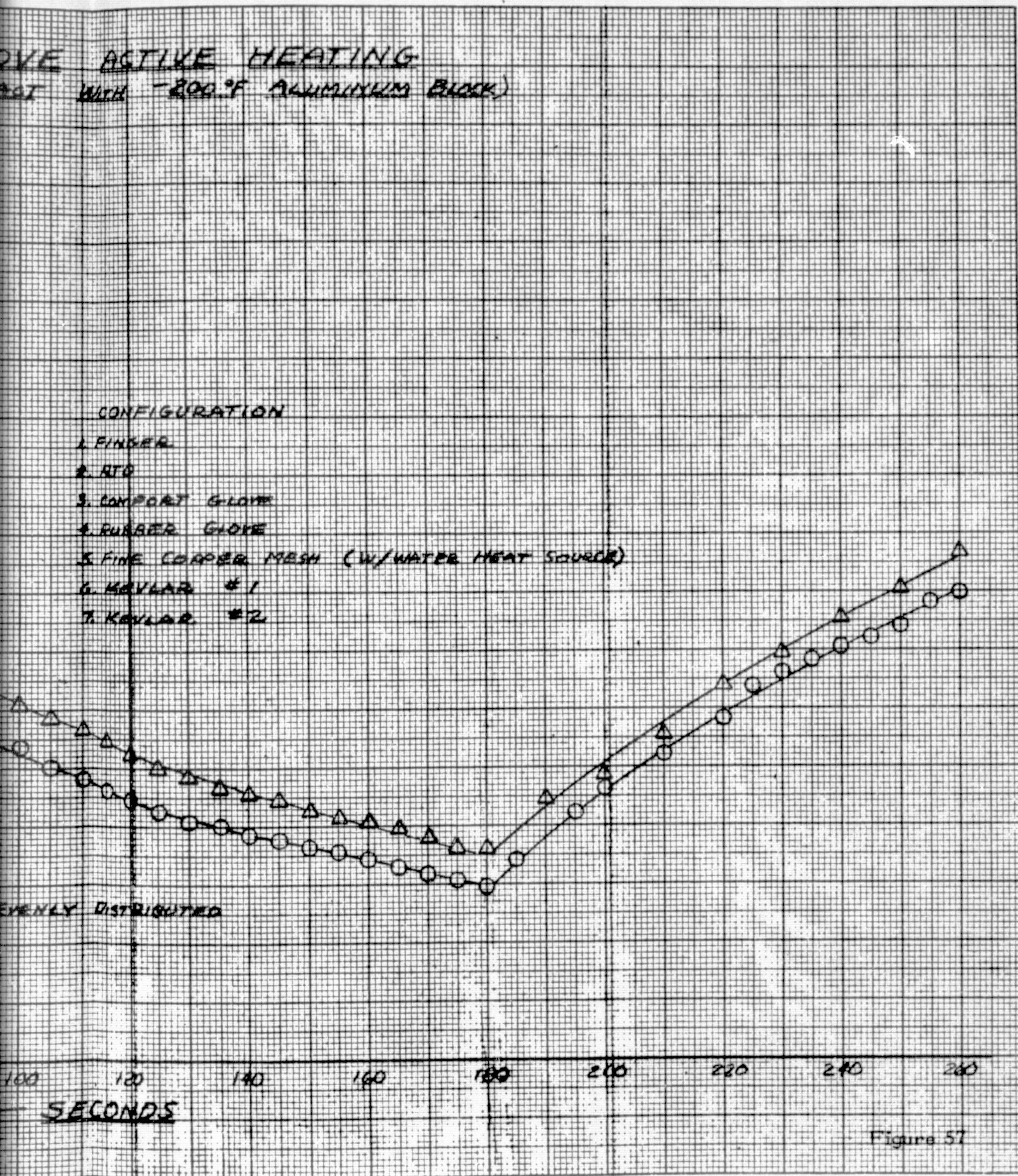
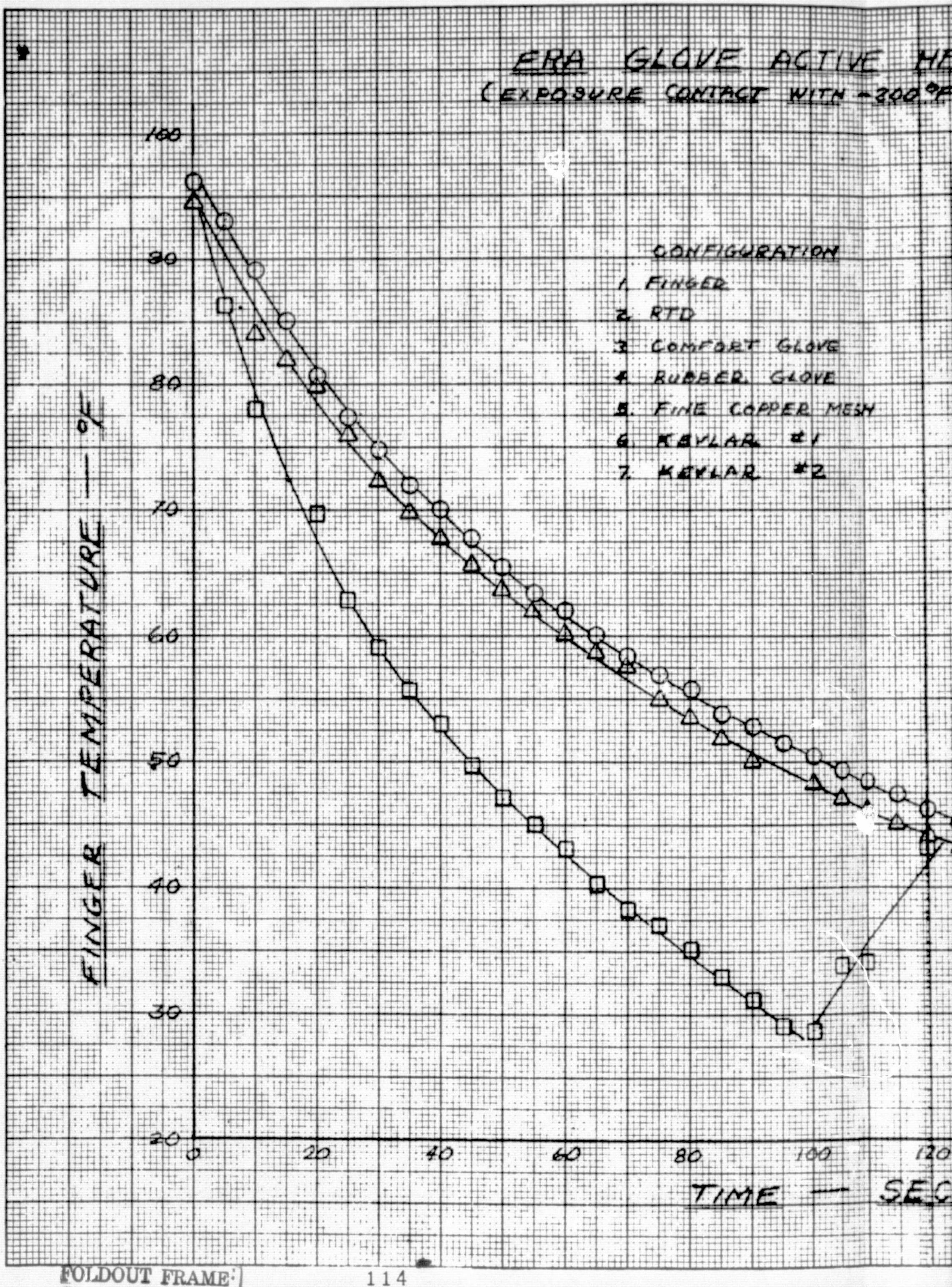


Figure 57

FOLDOUT FRAME 2



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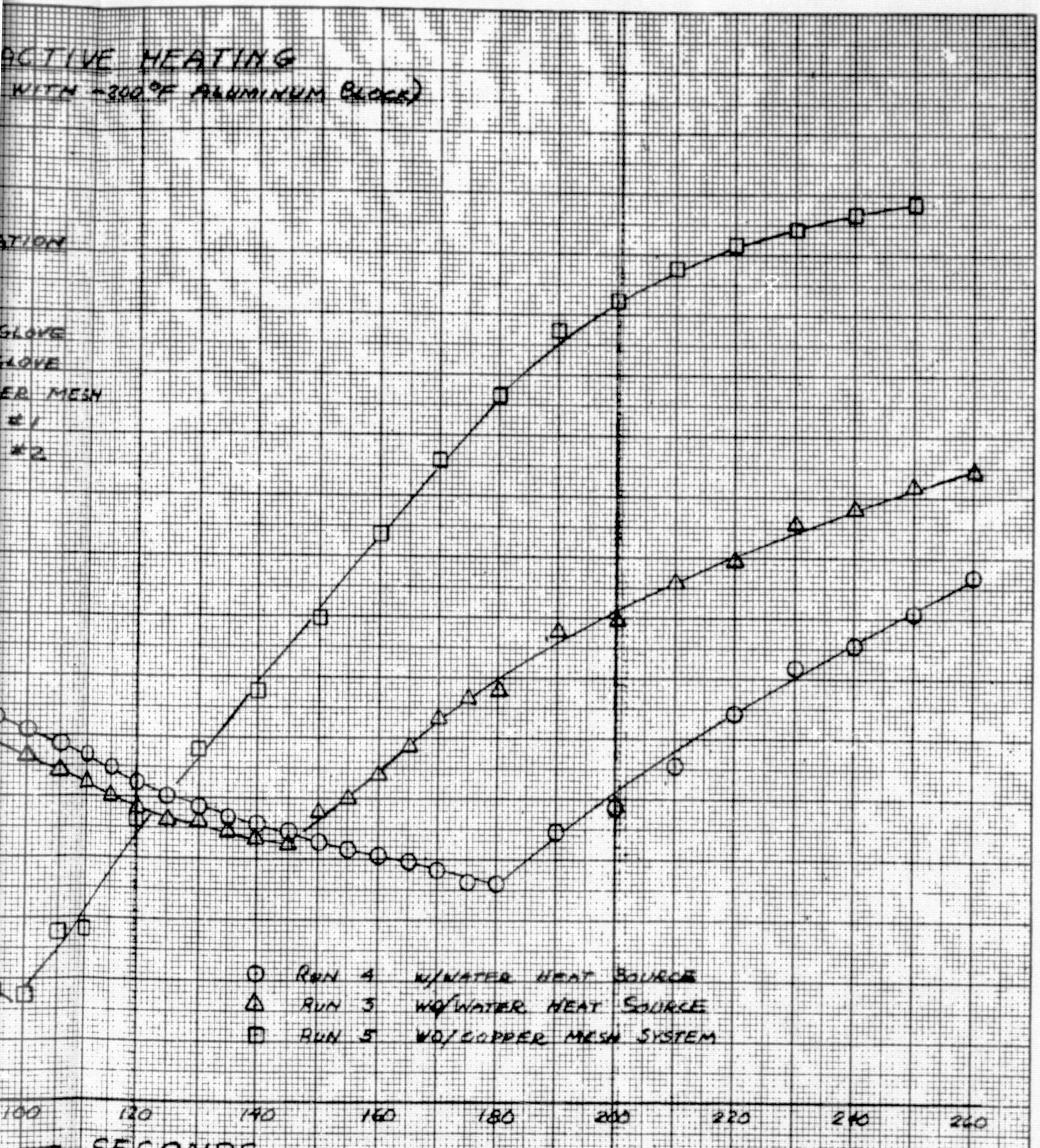
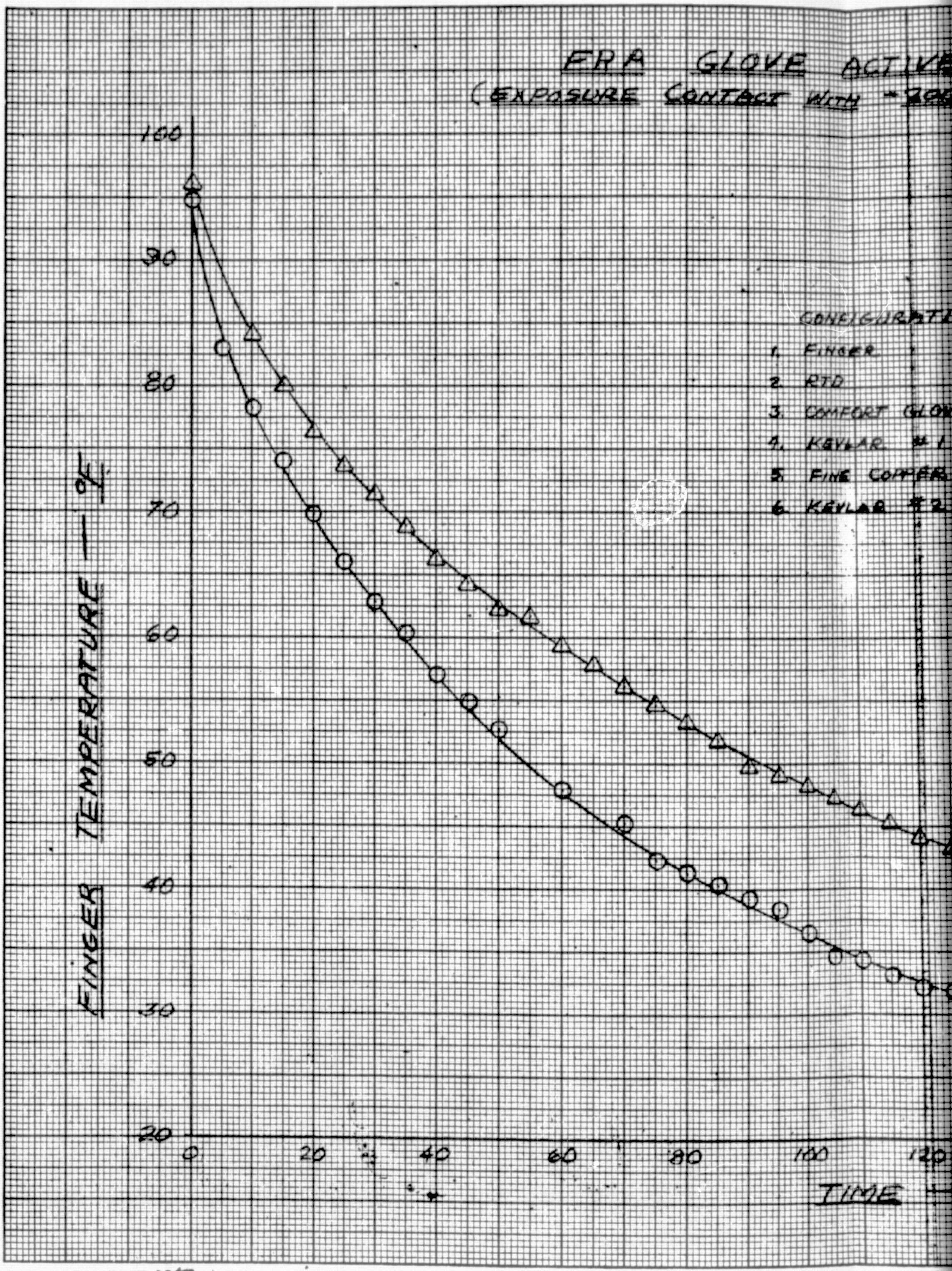


Figure 58

FOLDOUT FRAME 2



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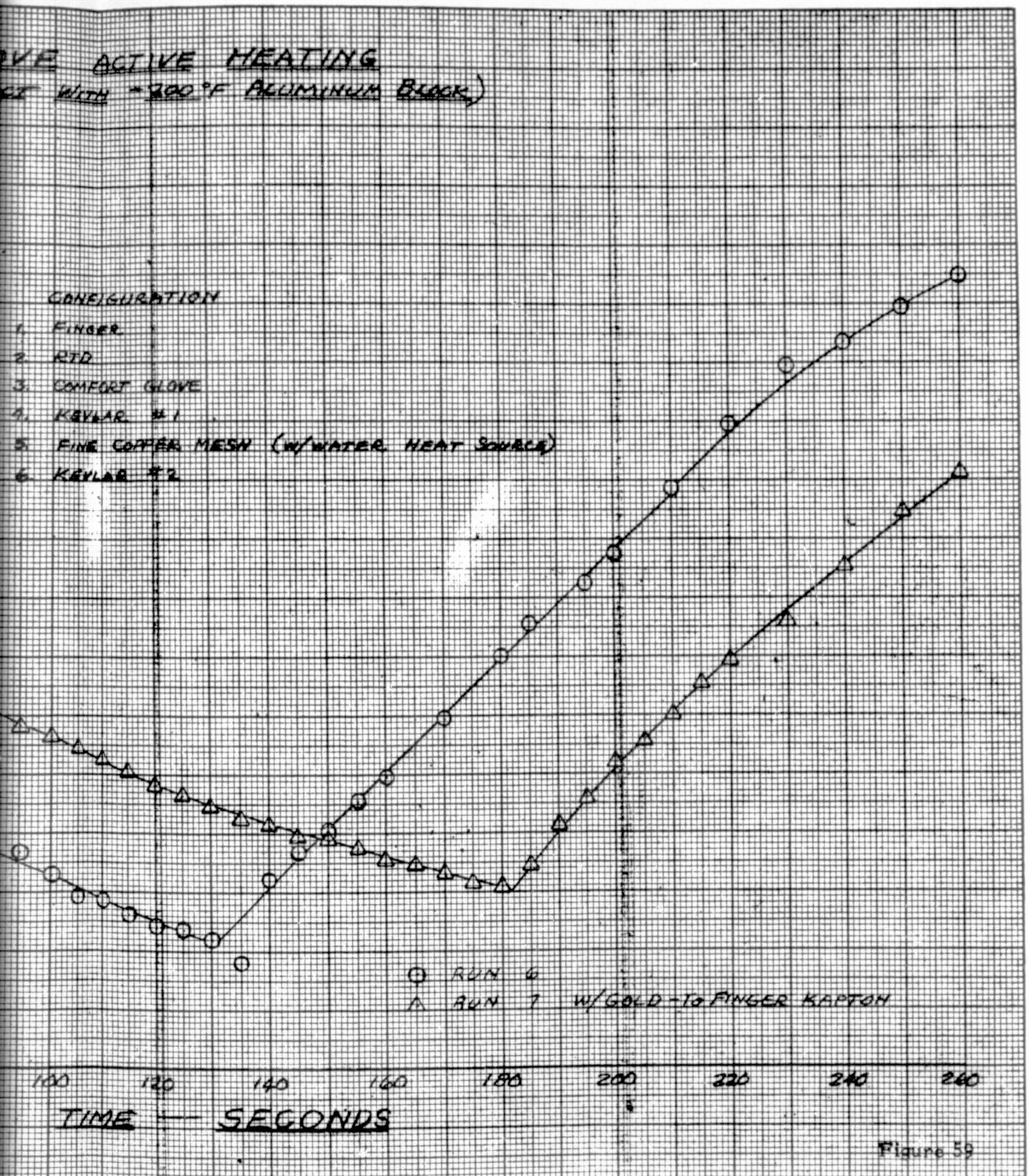


...OVE ACTIVE HEATING
...CT WITH -200°F ALUMINUM BLOCK)
CONFIGURATION
1. FINGER
2. RTD
3. COMFORT GLOVE
4. KEVLAR #1
5. FINE COPPER MESH (W/WATER HEAT SOURCE)
6. KEVLAR #2
RUN 6
RUN 7 W/GOLD-TO FINGER KAPTON
100
120
140
160
180
200
220
240
260
TIME — SECONDS

Figure 59

repeatability. Run 3 utilized only the stored thermal heat in the copper ropes and copper heat exchanger. This run had to be terminated at 145 seconds due to subject discomfort, indicating the thermal transfer rates were occurring in excess of what might be expected from the finger temperature data alone. Run 5 produced just the opposite effect. The higher transfer rates occurring without the copper thermal sink apparently caused numbing to the extent that discomfort was not objectionable until surface tissue was actually frozen. A second degree burn developed in this subject several hours after the test. Also activation is evident from the increased slope of the recovery curve.

The positioning of the copper wire fan was moved to the outside of one Kevlar insulating layer in Run 6. This configuration allowed more of the conductive heat to flow into the cold block with the net result being a marked degradation in performance. Run 7 was to compensate for the degradation by adding a layer of metalized Kapton.

It was decided to include one or more layers of radiation control insulation in the glove and to ignore radiation in analysis of the equivalent circuit. Data supporting this conclusion can be found in Figure 60, Total Black Body Radiation vs. Temperature. Assuming at least one layer of gold metalized Kapton properly oriented for the heating and cooling systems, the lower curve can be used to approximate radiation effects. For the cold bar, a radiation loss of approximately 0.00024 calories per square centimeter per second can be expected (0.00025 @ 100°F - 0.0000 @ -200°F). For the hot bar test condition, the radiation gain

TOTAL BLACK BODY RADIATION VS. TEMP.

$$W_T = \int_0^\infty w\,d\lambda \left(\frac{\text{WATTS}}{\text{CM}^2}\right)$$

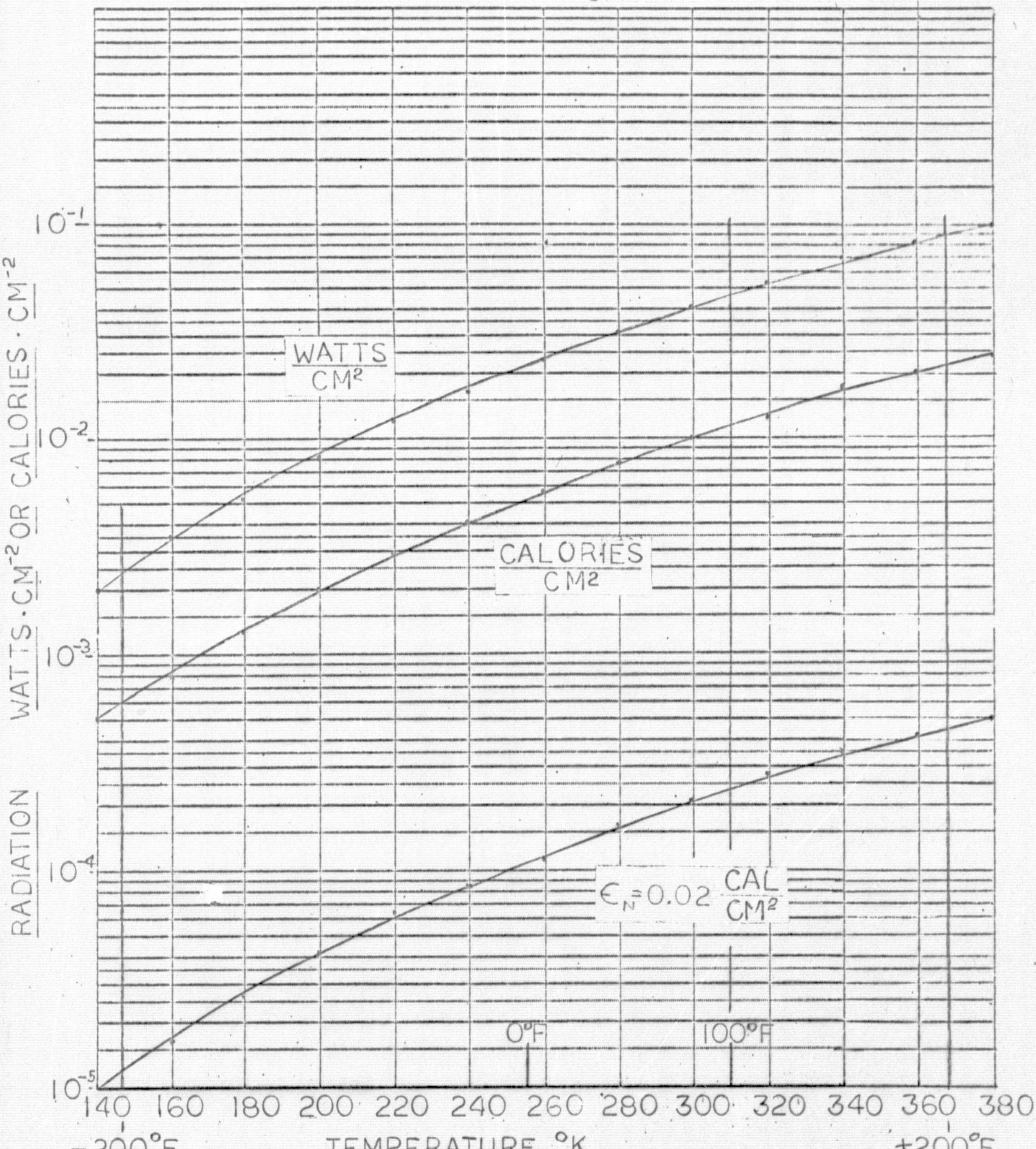


Figure 60

will approximate 0.00028 calories per square centimeter per second. Hand equivalents (for the 5 square in. contact area) are approximately 1.4 calories loss and 1.63 calories gain, respectively.

Hand Energy vs. Time

The actual hand energy supplied per unit time is highly variable. Some of the major factors influencing both the amount and the time distribution of this amount are:

1) Physiological and anatomical differences;
2) Test insulation properties;
3) Heating and cooling system operation, and
4) Load conditions.

It was felt, however, that a brief comparison with a pure exponential would be useful. Two (2) approaches were taken. The first of these was to assume that the curve of heat loss vs. time was a pure exponential and that the test block would reach physiological heat equilibrium at 95°F, much like an electronic circuit charging to a fixed potential. The maximum energy value was then calculated from

$$Q\,(max) = K\ m\ Cp\ So\ \Delta T = 62.3 \text{ calories} \quad \text{-----------} \quad (1)$$

where $K = 5^{\circ}C/9^{\circ}F$

m = A1 test block mass = 8.69 grams

Cp = Specific heat of A1 = 0.2154

So = Maximum slope = $1^{\circ}F/Sec$

ΔT = Maximum temperature change = $60^{\circ}F$.

The RC time constant was determined by finding the time at which finger energy loss (block temperature gain) equaled the 63.21%

point for Q max, or 39.4 calories. Thoretical test block heat gains were then caluclated from

$$q(t) = Q\ max\ (1 - e^{-t/RC}) \text{ ------------------ } \quad (2)$$

where: Q max = 62.3 calories

RC = 116 seconds

A comparative curve of actual test data and the solution of equation (2) are shown in Figure 61. The error at 180 seconds is approximately 3 calories, and the maximum error appears to be around 4 calories utilizing this approach. Caloric values listed are for 5 square centimeters of finger area @4.75 pounds per square in. contact pressure.

The second analytical approach also assumed a pure exponential form but asked the question "What is the change in the RC time constant as a function of time?" Such an approach facilitates both discrete point multi-nodal analysis and segmental curve fitting in addition to giving insight into physiological changes as a function of variable heat stress over-time.

Utilizing the same 3 subject thermal transfer data as before, the RC time constant was calculated at a few points utilizing the equation

$$RC = \frac{t}{K,\ \ln\left(\frac{So}{S\ (t)}\right)} \text{ ---------------- } \quad (3)$$

R = Thermal resistance = $\left(\frac{{}^{o}F\ sec\ cm^{2}}{calorie}\right)$

C = tissue thermal capacity = m Cp $\left(\frac{calorie}{{}^{o}C}\right)$

T = time in seconds

So = initial slope = $\left(\frac{{}^{o}F}{Sec}\right)$

S(t) = slope at $\left(\frac{{}^{o}F}{Sec}\right)$

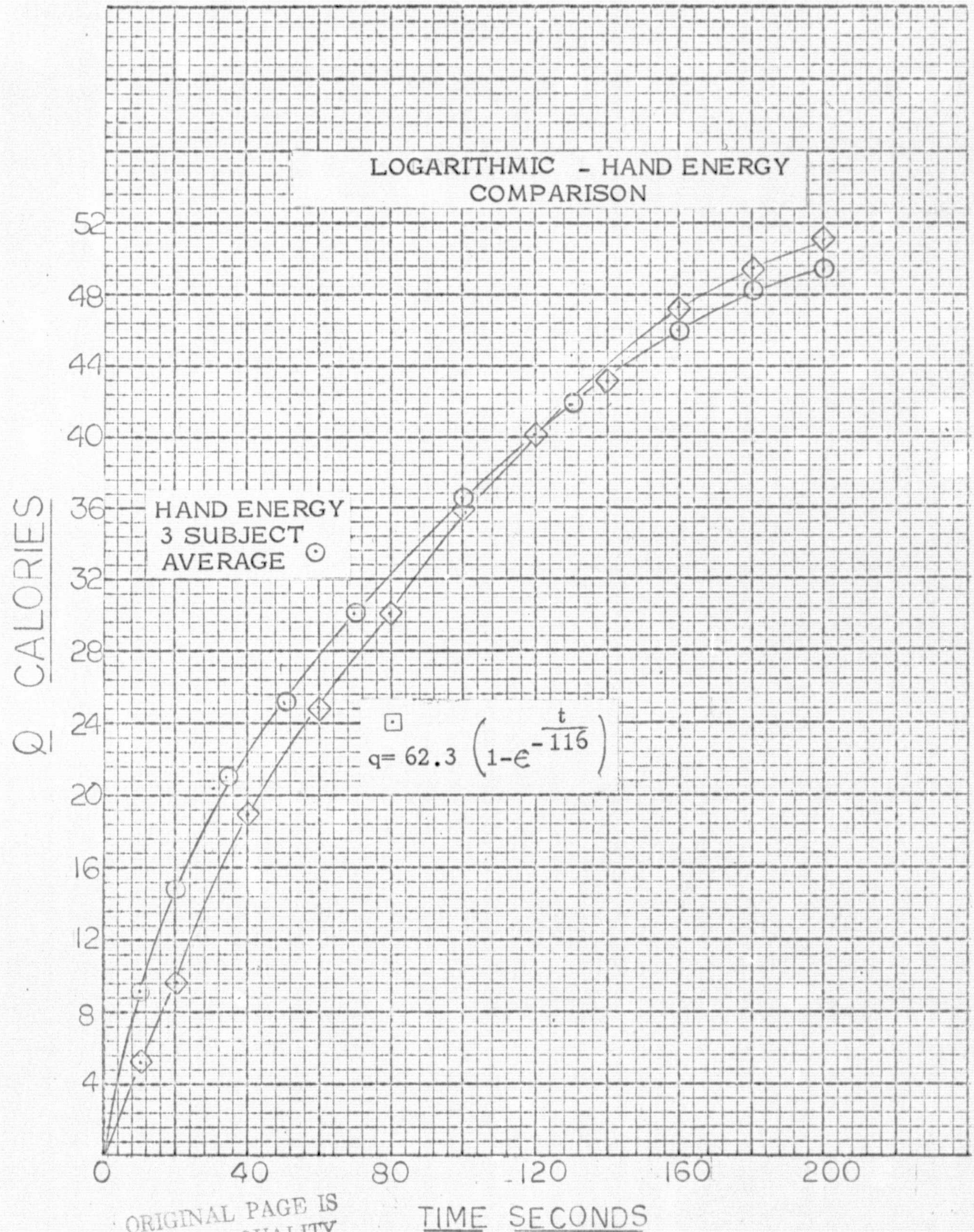

LOGARITHMIC - HAND ENERGY COMPARISON
HAND ENERGY
3 SUBJECT
AVERAGE
$q = 62.3 \left(1 - \epsilon^{-\frac{t}{116}}\right)$
Q CALORIES
TIME SECONDS
0
4
8
12
16
20
24
28
32
36
40
44
48
52
40
80
120
160
200

Figure 61

Data so obtained is shown in Table 3, Variation Of Tissue Thermal Time Constants. Both R and C are varying as the body reacts to thermal stress. However, the variation of R (equivalent thermal resistance) is probably much greater than C since the equivalent mass and specific heat of the fingers are relatively fixed. On the other hand, more and more tissue will become involved as localized heat loss gradually cools nearby tissue and thus causes the path of thermal heat flow to increase.

Initially, a series of tests were made using copper elements (active) on the finger with various heat sources integrally conducted to the finger elements or fans. An early active element unit is shown in Figure 37, (see Glove Cooling System section). The heat source was air warmed. Test data are shown on Figure 62. The "Copper Ring in Water" test is simulative of a wrist water filled torus stabilized at a relative high suit temperature. "The Copper Ring in Air" is somewhat representative of a solid ring or fan cooled by suit air flow. While considered "quite cool" at 200 seconds for both tests and "very cold" at 260 seconds for test 6-22, pain was not reported at 300 seconds for either of the tests. In addition normal finger color was achieved immediately following the test.

These initial successes led to concepts utilizing the hand dorsal surface as an intermediate thermal storage and physiological transfer point, Figure 40 (see Glove Cooling System section). Test data are shown on Figure 63 for the glove heating mode.

The preceding tests had demonstrated that fine flexible copper wire elements, placed in contact with the skin, could act as heat active

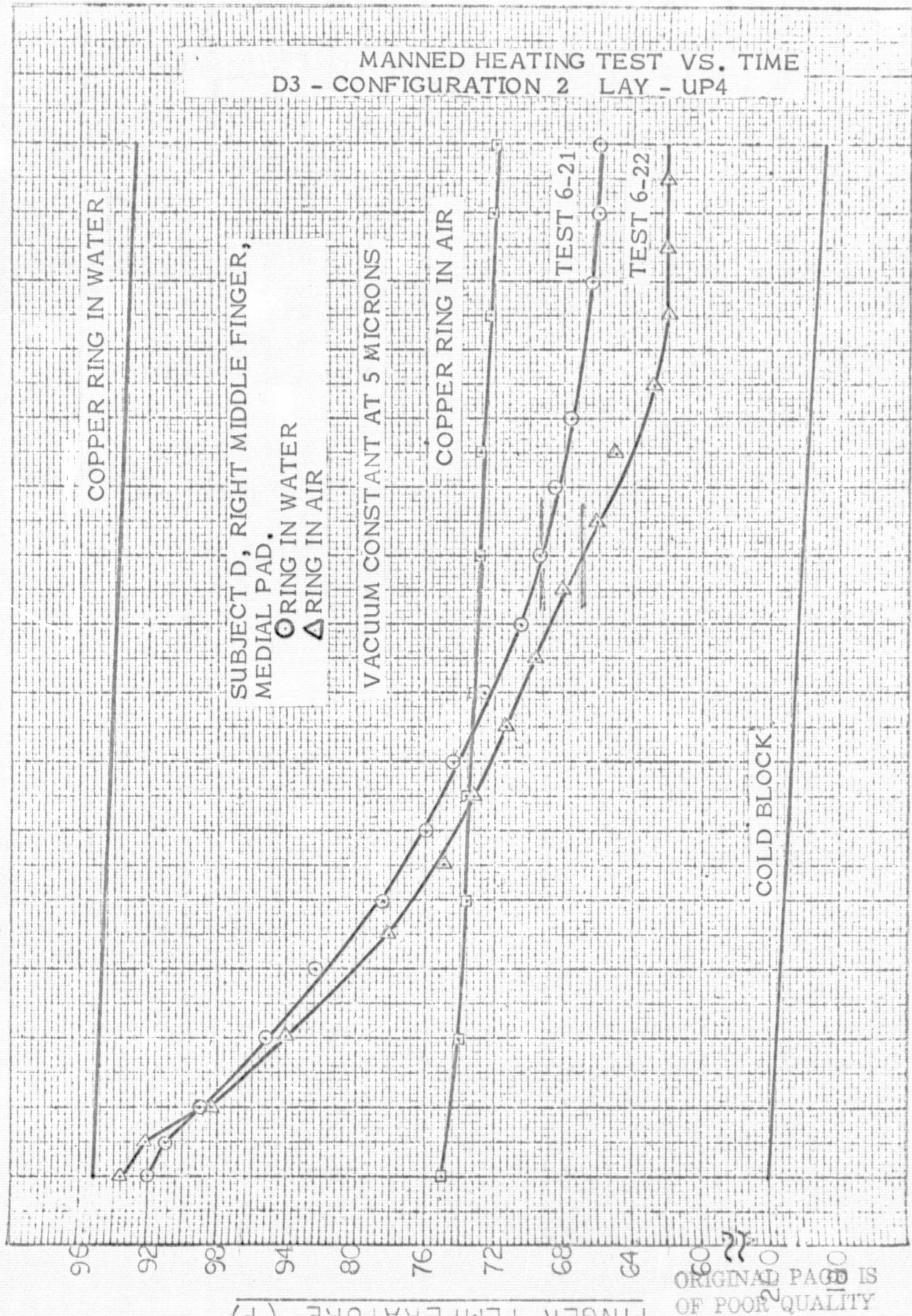

MANNED HEATING TEST VS. TIME
D3 - CONFIGURATION 2 LAY - UP4
COPPER RING IN WATER
SUBJECT D, RIGHT MIDDLE FINGER, MEDIAL PAD.
RING IN WATER
RING IN AIR
VACUUM CONSTANT AT 5 MICRONS
COPPER RING IN AIR
TEST 6-21
TEST 6-22
COLD BLOCK
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
TIME (SECONDS)
96 92 88 84 80 76 72 68 64 60 20 10
FINGER TEMPERATURE (°F)

Figure 62

VARIATION OF TISSUE THERMAL TIME CONSTANTS

TIME (Seconds)	1 S (t) (°F/Sec.)	2 $\frac{So}{S(t)}$	3 ln ②	4 RC (Sec°Cm²)
0	1	1	0	--
10	.8	1.25	.223	80.64
25	.44	2.273	.821	54.81
50	.25	4	1.386	64.93
75	.1973	5.068	1.623	83.18
100	.154	6.494	1.872	96.21
145	.1133	8.826	2.178	119.85
180	.090	11.111	2.408	134.55

$$R \; @ \; t = 0 = \frac{A \triangle T \; MAX}{K_1 \; MCp \; So} = 288.5 \; \left(\frac{^{\circ}F \; sec. ^{\circ}Cm^2}{Cal}\right)$$

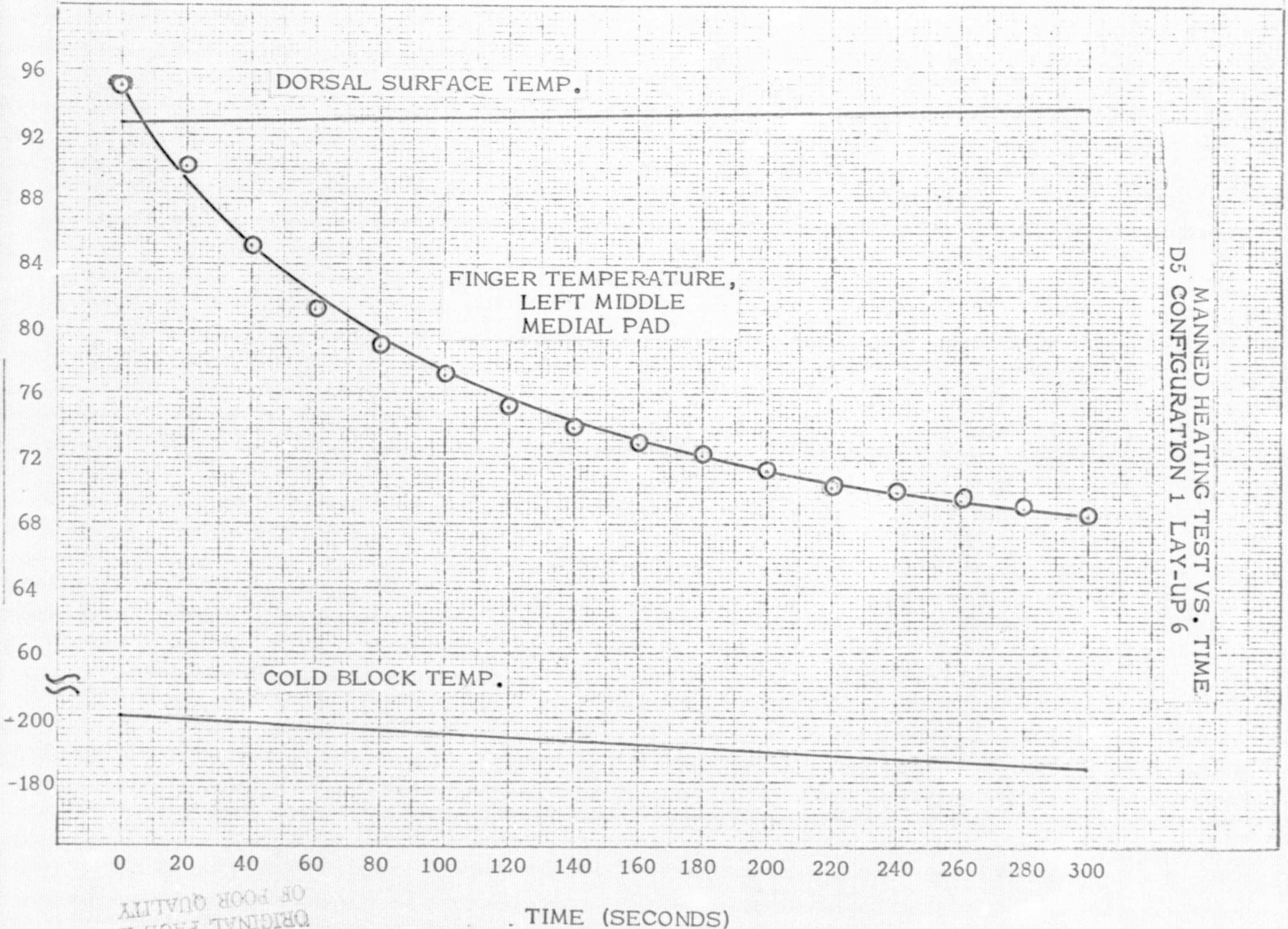
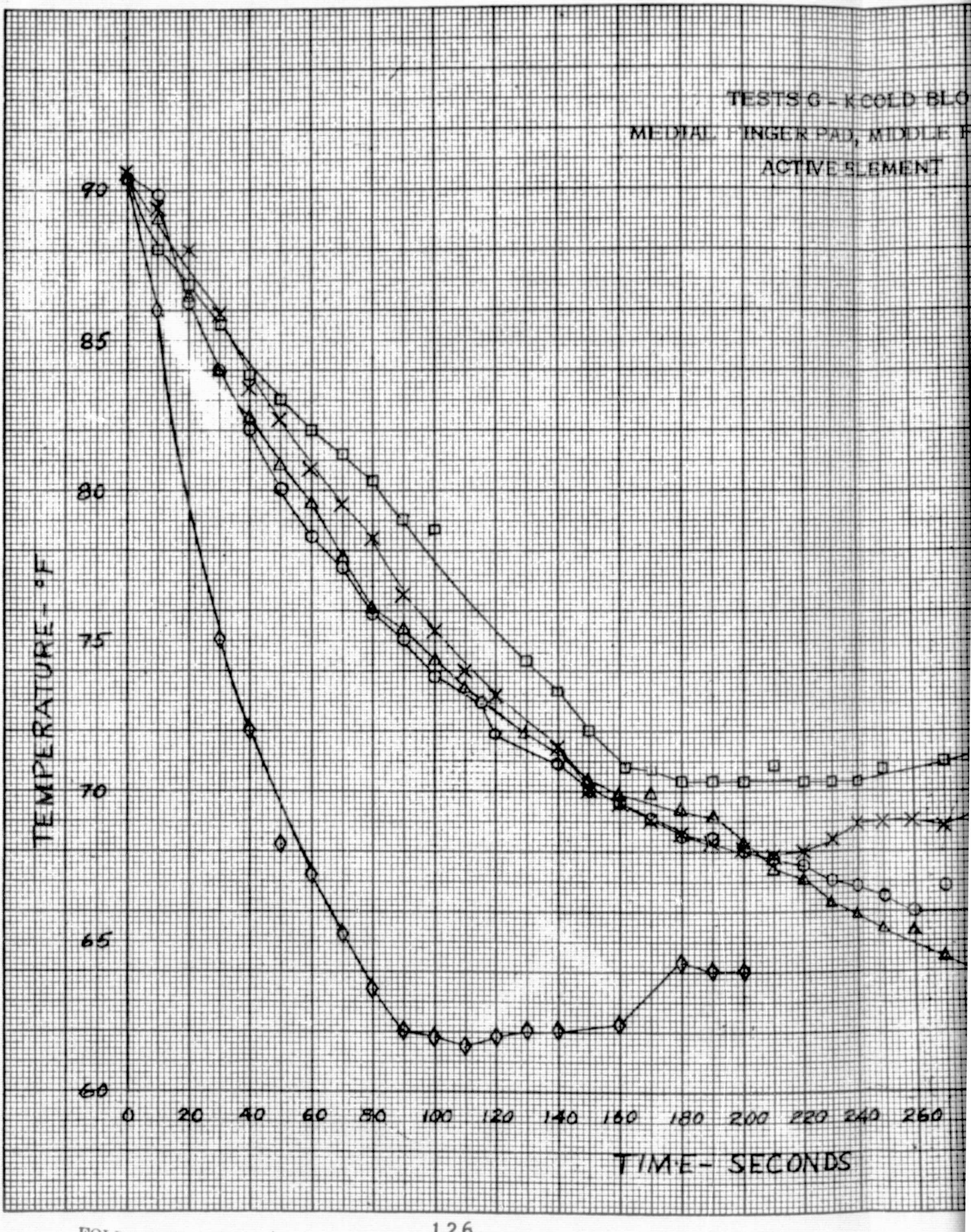

MANNED HEATING TEST VS. TIME
D5 CONFIGURATION 1 LAY-UP 6
DORSAL SURFACE TEMP.
FINGER TEMPERATURE, LEFT MIDDLE MEDIAL PAD
COLD BLOCK TEMP.
TEMPERATURE (°F)
96
92
88
84
80
76
72
68
64
60
-200
-180
TIME (SECONDS)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300

Figure 63

transport elements. This allowed the heating effects of circulating blood to warm the fingers during exposure to a cold surface. Tests (G) through (K) were conducted to determine which skin areas and active elements (fan configurations) would be most efficient. The cold bar temperatures for this series of experiments varied from -195°F to -210°F. The vacuum levels in the insulation patch, (see Figure 43, model MP-2 patch) varied from less than 1.0 micron to 15.0 microns. All tests were run with a layer of comfort glove (GFE) next to the skin and a layer of comfort glove plus a rubber sheet (to simulate the rubber glove membrane) covering the fan configuration. The finger was pressed on the cold bar with a force of 3.7 pounds. Data from this series of tests are plotted on Figure 64.

All tests were run with fans and connections made of very flexible pure copper wire (99.99%). The "ropes" Figure 44 are 16 gauge wire with a 2660 circular mil area. These wires are composed of seven wires, each of which is made up of three wires, in turn comprised of about 32 wires, .002 in. diameter wires. The total number of small (.002 in. diameter) wires is 665. The weight is .00067 lbs/ inch or .119 grams/ cm.

In the first test (G) of this series, using a cold body at -200°F, a Kapton two rope assembly (Figure 44), having approximately 2.2 in^2 area at the back of the hand, was used with the finger pad placed in the medial position of the middle finger, as shown in Figure 64, the finger temperature was 68.5°F at 180 seconds, and 65.2 at 400 seconds. Test (H) was identical to Test (G), except the back-of-the-hand fan was insulated from the hand and therefore was essentially at room temperature. As shown in Figure 64, the finger temperature was 69.3°F at 180 seconds, and 62.4°F at 400 seconds.



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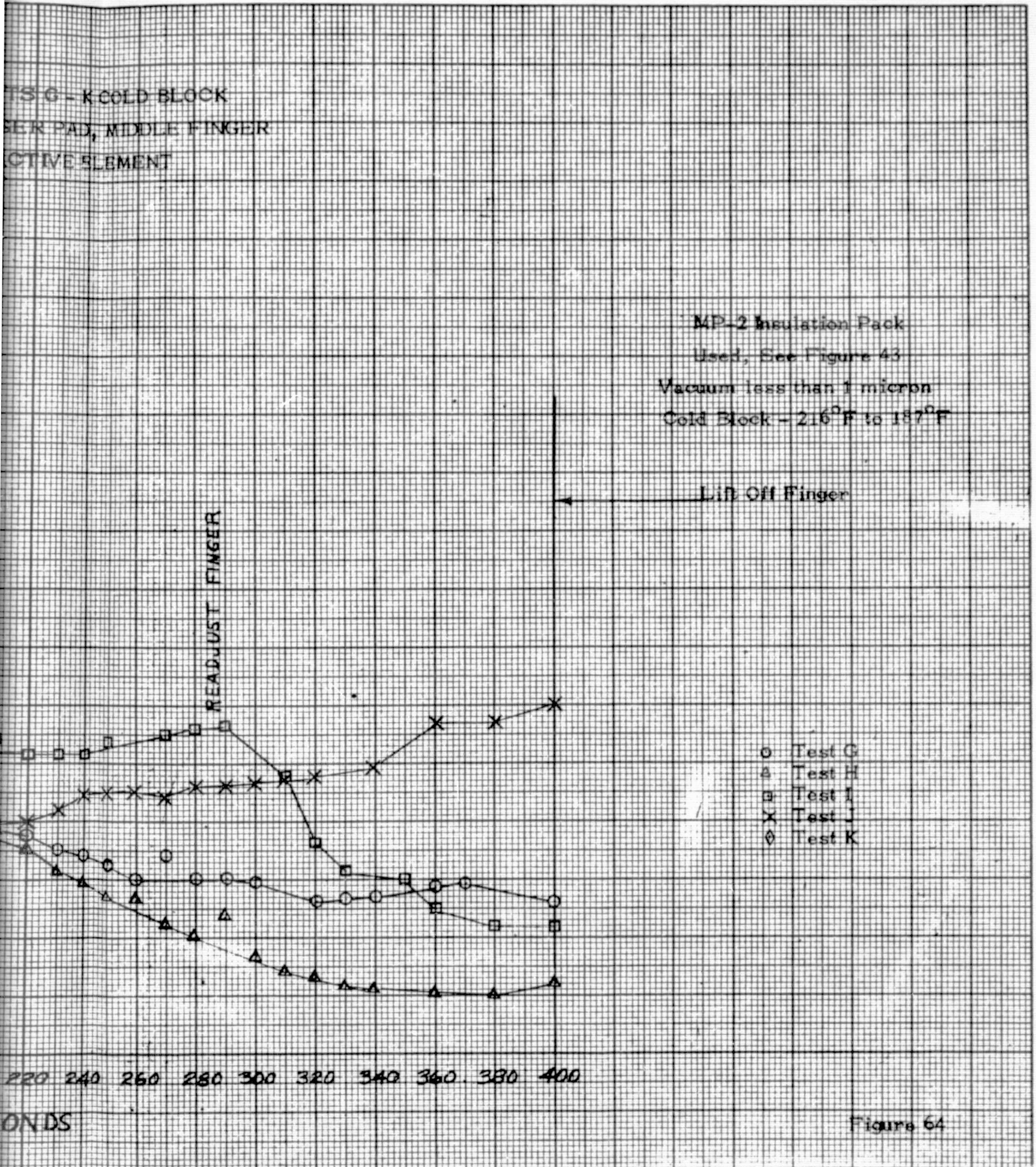
TS G - K COLD BLOCK
ER PAD, MIDDLE FINGER
CTIVE ELEMENT
MP-2 Insulation Pack
Used, See Figure 43
Vacuum less than 1 micron
Cold Block - 216°F to 187°F
Lift Off Finger
READJUST FINGER
Test G
Test H
Test I
Test J
Test K
220 240 260 280 300 320 340 360 380 400
ONDS

Figure 64

In the succeeding tests, the copper conducting elements were progressively reduced in area and size. See Figure 44 for the cut points prior to testing, (I through K).

In test (I), the finger temperature was $70.3^{\circ}F$ at 180 seconds, and 64.3 at 400 seconds.

In test (J), with only the finger fan remaining, the finger temperature was $69.6^{\circ}F$ at 180 seconds and $72.0^{\circ}F$ at 400 seconds.

A control test no. III was made using a non conducting material (fine Kevlar fibers) finger fan similar in thickness to the copper fan. This test was made to determine the effect of having a non conductor at the finger pads. The "stand off" in itself provides a type of thermal barrier. This was a cold body test and it had to be terminated at 120 seconds due to extreme cold sensed. The recorded temperature was $65.5^{\circ}F$ at $120^{\circ}F$ (Figure 65). Again the high temperature rate of change coupled with a low temperature made it difficult to withstand. This test shows that the copper elements are supplying heat to the finger pads and that they did not function only as a material "stand off" between the finger and the cold body.

The preceding tests showed that finger fans (active elements), only, did the best job of providing additional heat to the finger pads. These finger fans only partially circumscribed the finger. Thus it was evident that fully circumscribing active elements would provide more heat to the finger pads

A series of cold block tests was conducted using the full

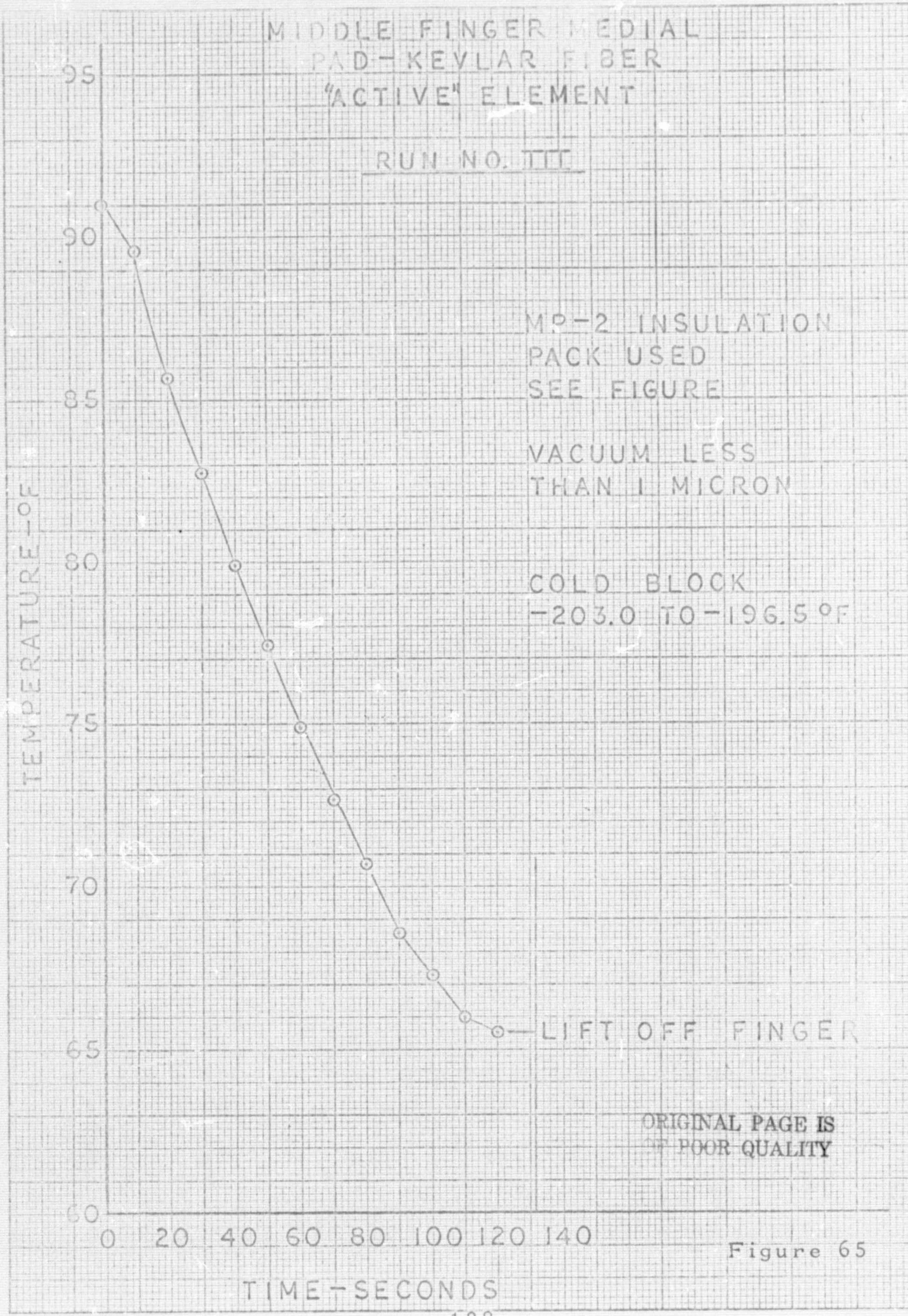

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Figure 65

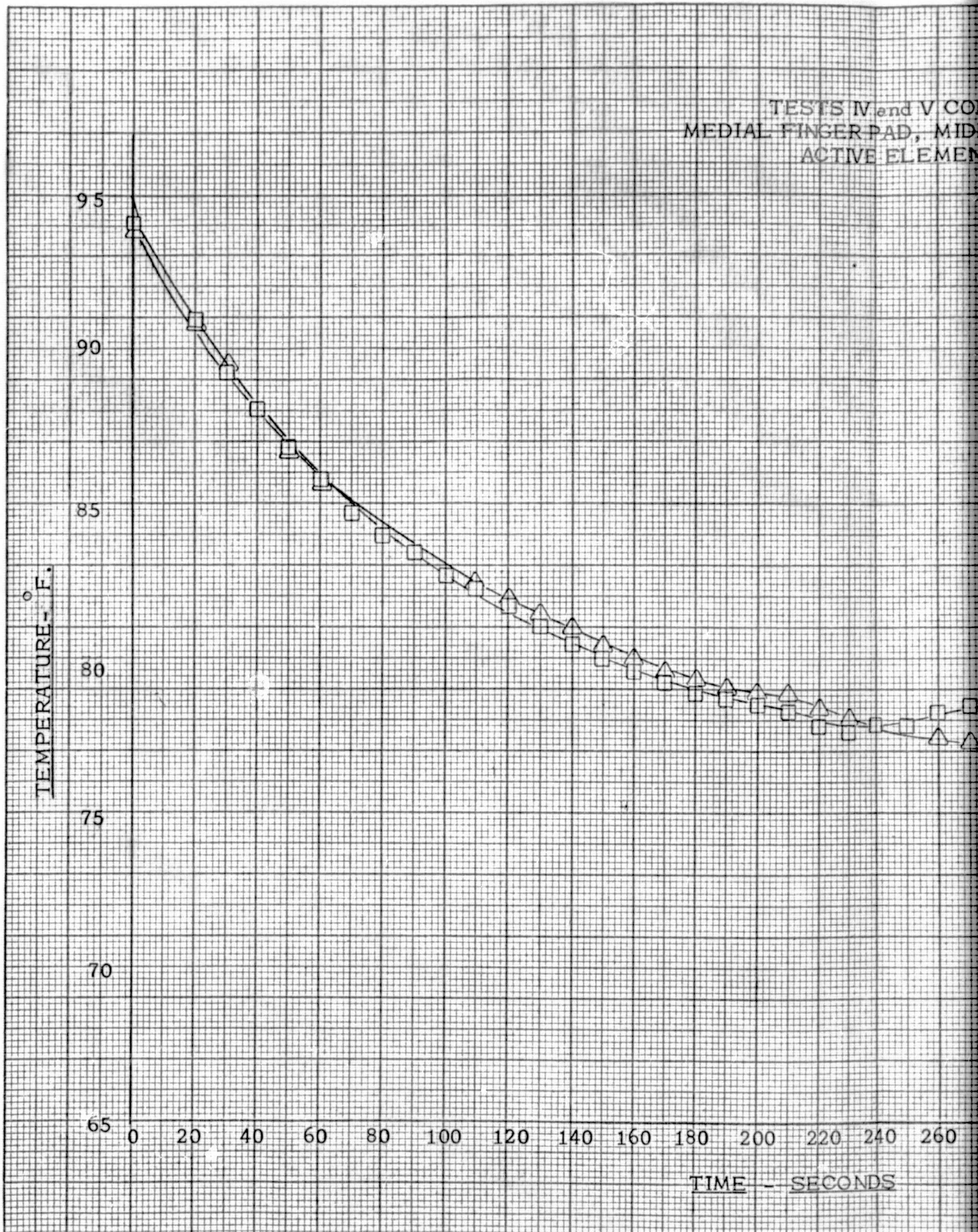
circumscribed active copper-Kapton elements which were covered on both sides with GFE comfort glove material. A rubber glove covered the finger elements in most tests. A standard insulation MP-2 pad (Figure 43) was used. Finger pressure in most tests was 3.75 pounds. During these tests, the vacuum in the insulation pad was less than one micron. The cold block temperature during 400 seconds varied from -216.5°F to -187.0°F.

Test IV, with one circumscribing finger element (2.05 grams weight), located at the medial pad of the middle finger, had a starting middle finger medial pad temperature of 93.7°F, at the end of 180 seconds, the finger temperature was 79.4°F and at 400 seconds it was 76.5, Figure 66.

Test V was a duplicate of Test IV except the starting finger temperature was slightly higher (93.9°F). At 180 seconds the middle finger medial pad was 78.8 °F and at 400 seconds, the finger temperature was 84.0°F, Figure 66.

Two circumscribing elements were used in Test VII. The proximal element weighed 2.14 grams and the distal element weighed 2.05 grams. These elements were attached to a comfort glove, (for this test and all succeeding tests) in the same manner as the final glove. The proximal RTD sensor broke during the experiment, so only the terminal pad finger temperature was recorded, Figure 67. At the end of 180 seconds, the finger temperature was 79.8°F and it was 80.1°F at 400 seconds.

Test VIII data is also shown in Figure 67. Only the proximal temperature was recorded, because instrumentation failed to properly record the distal data. The proximal finger pad temperature was 72.5°F at 180



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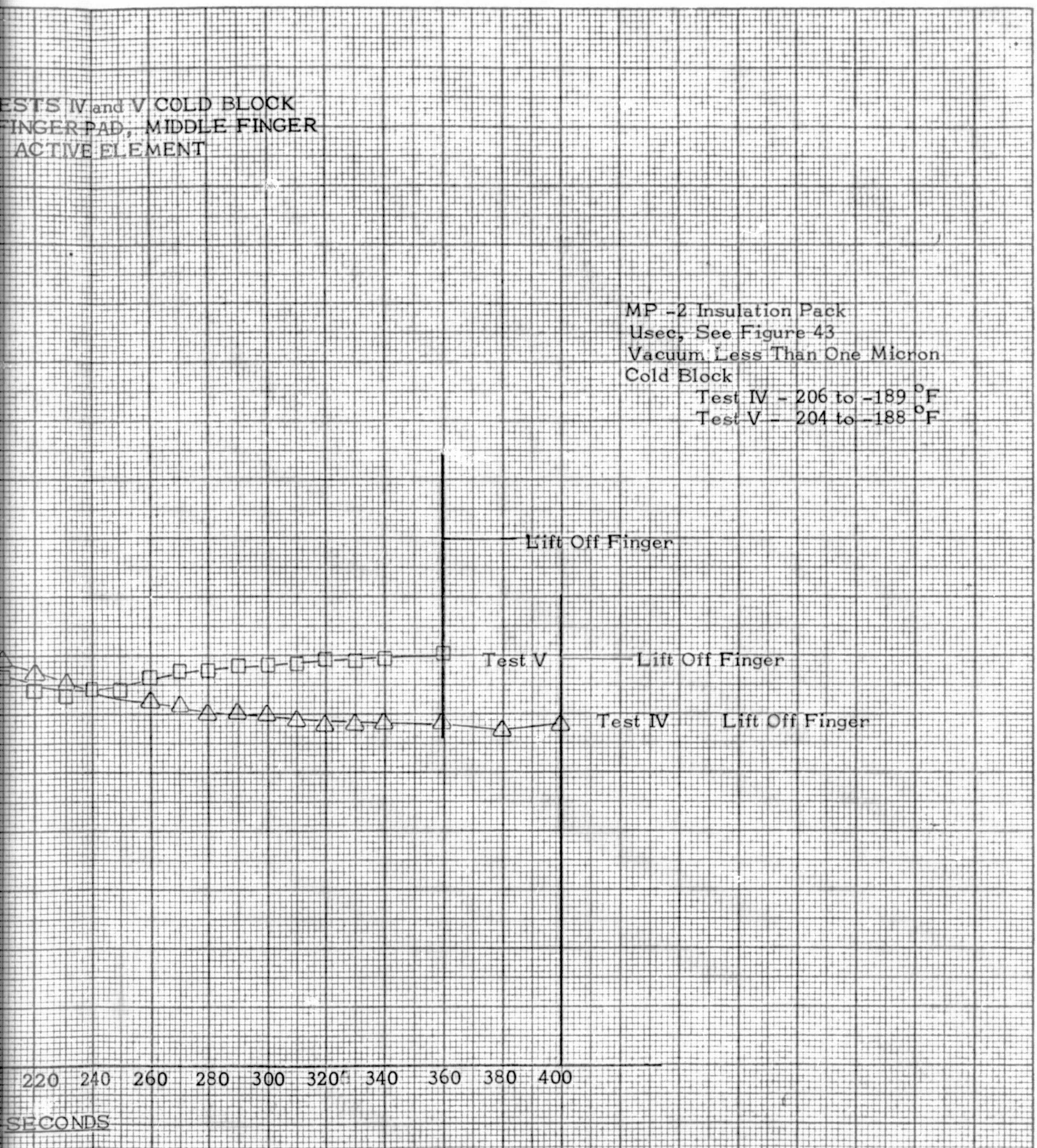
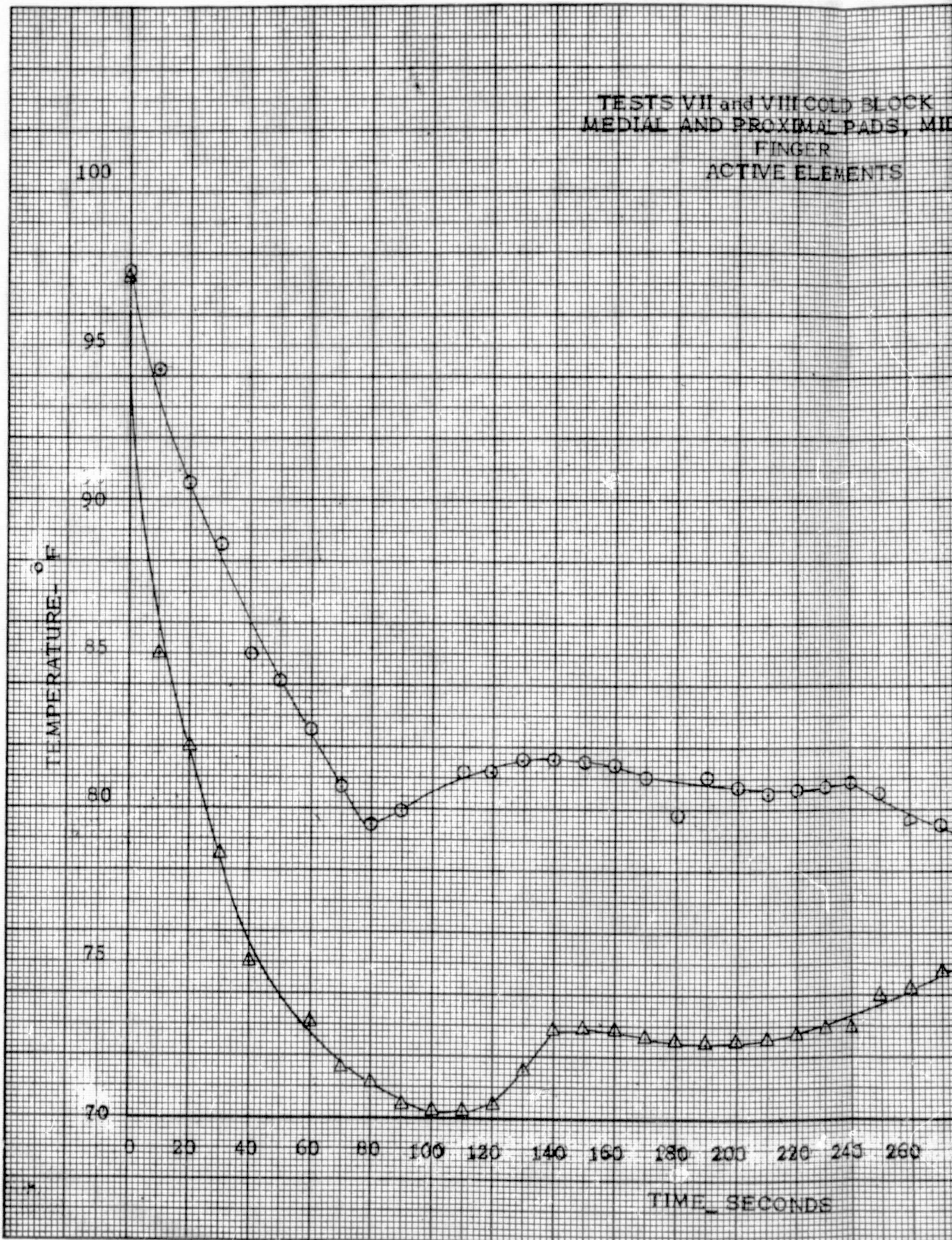

ESTS IV and V COLD BLOCK
FINGER PAD, MIDDLE FINGER
ACTIVE ELEMENT
MP -2 Insulation Pack
Usec, See Figure 43
Vacuum Less Than One Micron
Cold Block
Test IV - 206 to -189 °F
Test V - 204 to -188 °F
Lift Off Finger
Test V
Lift Off Finger
Test IV
Lift Off Finger
220
240
260
280
300
320
340
360
380
400
SECONDS

Figure 66



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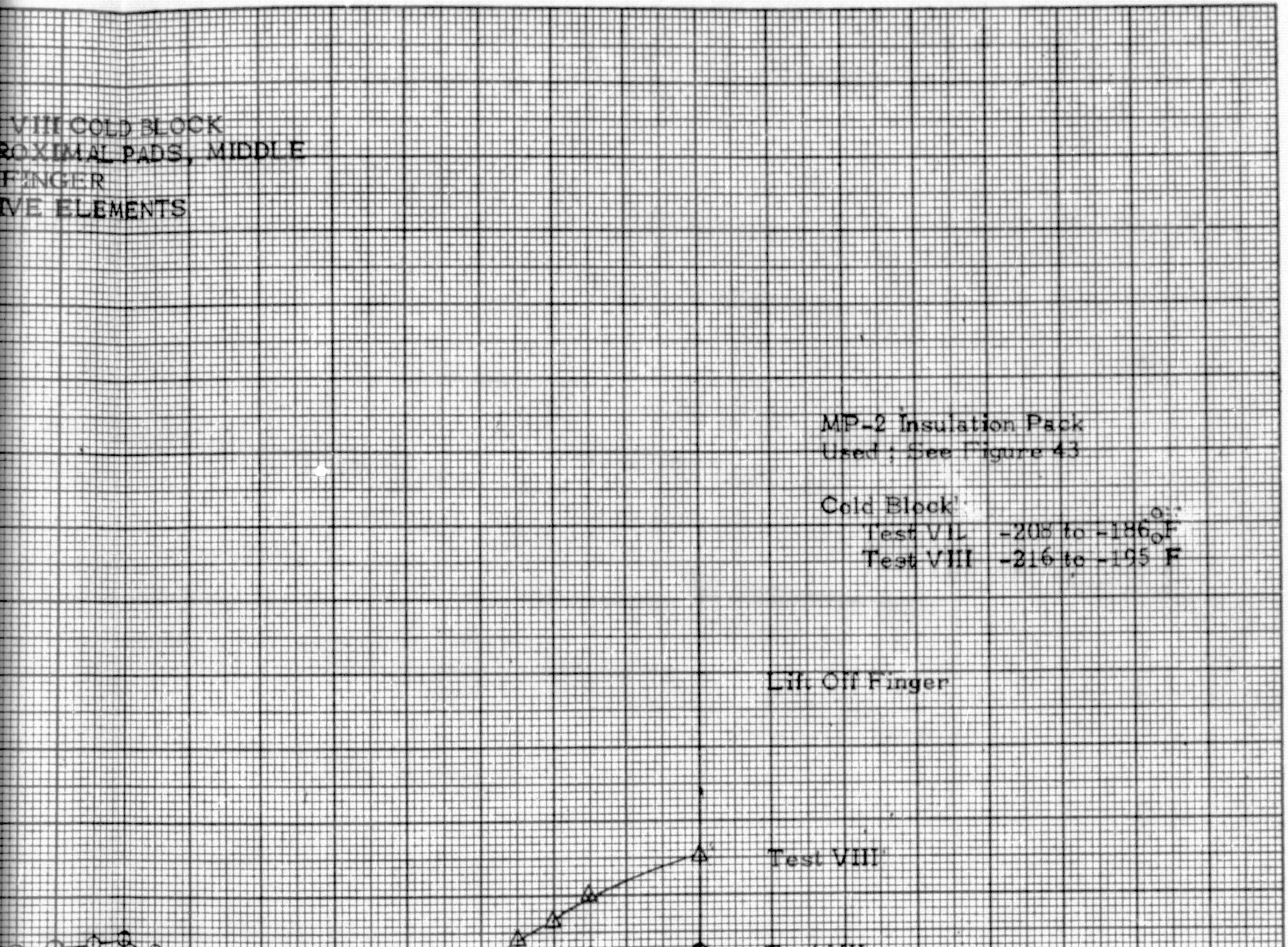

Figure 67

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seconds and 83.0°F at 400 seconds. The starting finger temperature was higher in this test, and remained warmer during the entire test.

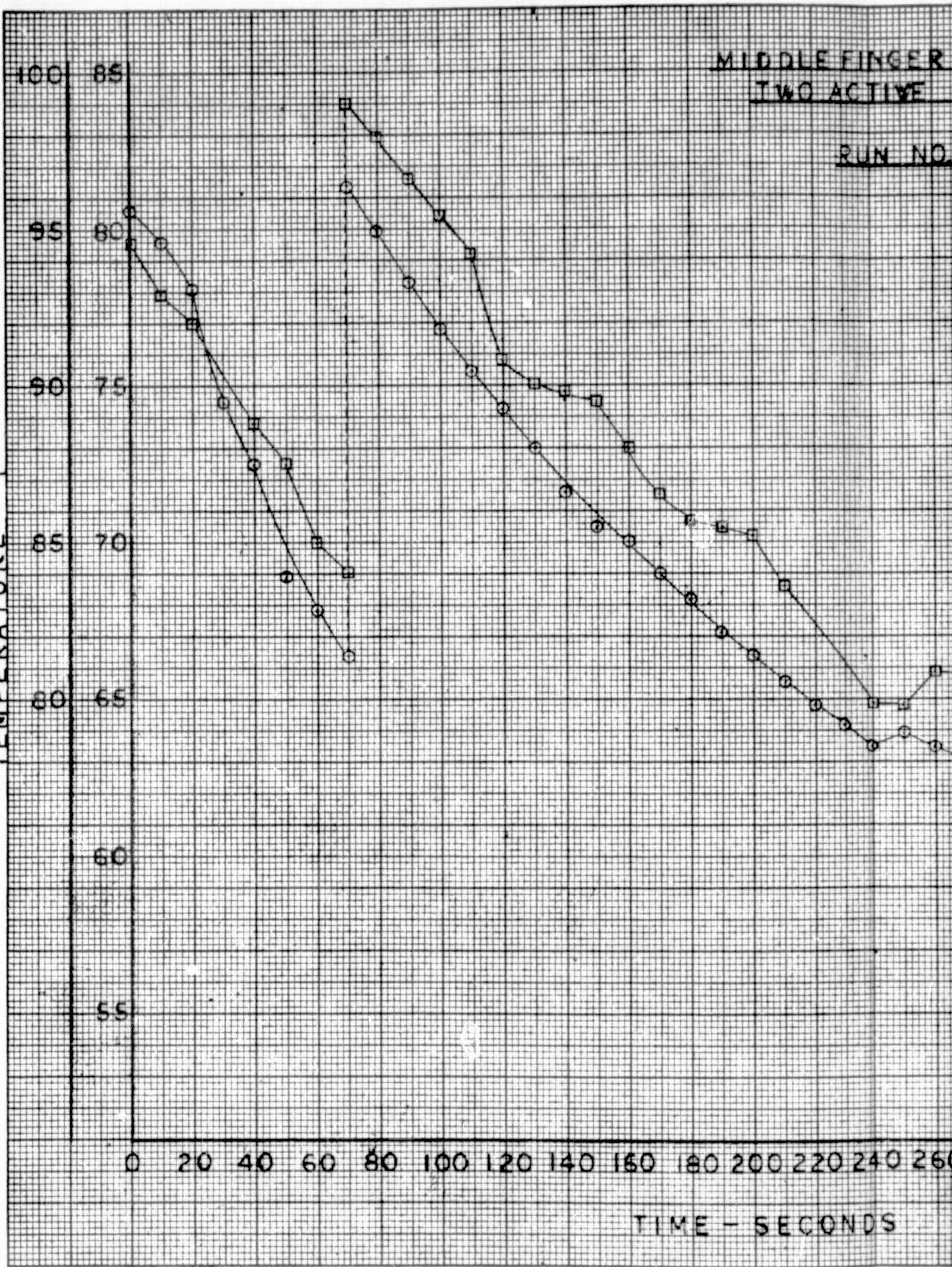
Test XII, Figure 68 was a two element pad test. The elements were covered with two layers of GFE comfort glove and a rubber membrane. At the end of 180 seconds, the medial finger pad temperature was 68.2°F, and at 400 seconds, 61.7°F. The proximal finger pad temperature was 70.7 at 180 seconds and 58.2 at 400 seconds. The cold bar temperature ranged from-208.5 to -215.6°F during this particular test.

Test XIII, Figure 69 was identical to the previous test. Two active elements were used. The starting medial pad finger temperature was 95.7°F and the proximal pad was 94.5°F. After 180 seconds, the medial padfinger temperature was 68.2°F and at 300 seconds it was 61.7°F, the proximal finger pad temperature at 180 seconds was 70.7 and at 300 seconds it was 60.0°F.

Test XIV was a two active element test. Data are presented in Figure 70. The medial finger pad starting temperature was only 89.7°F and the proximal finger pad was 89.5°F. After 180 seconds, the medial pad was 64.5°F and at 300 seconds, 70.1°F. At 180 seconds the proximal pad was 66.1°F, and at 300 seconds 66.6°F.

Following each of the above tests the finger was examined and found to be in normal condition.

The above tests indicate that the heating elements function as designed for 180 seconds and can in most cases function satisfactorily for 300 to 400 seconds. At this stage of development, the active element design was considered as suitable for incorporation into the final glove.



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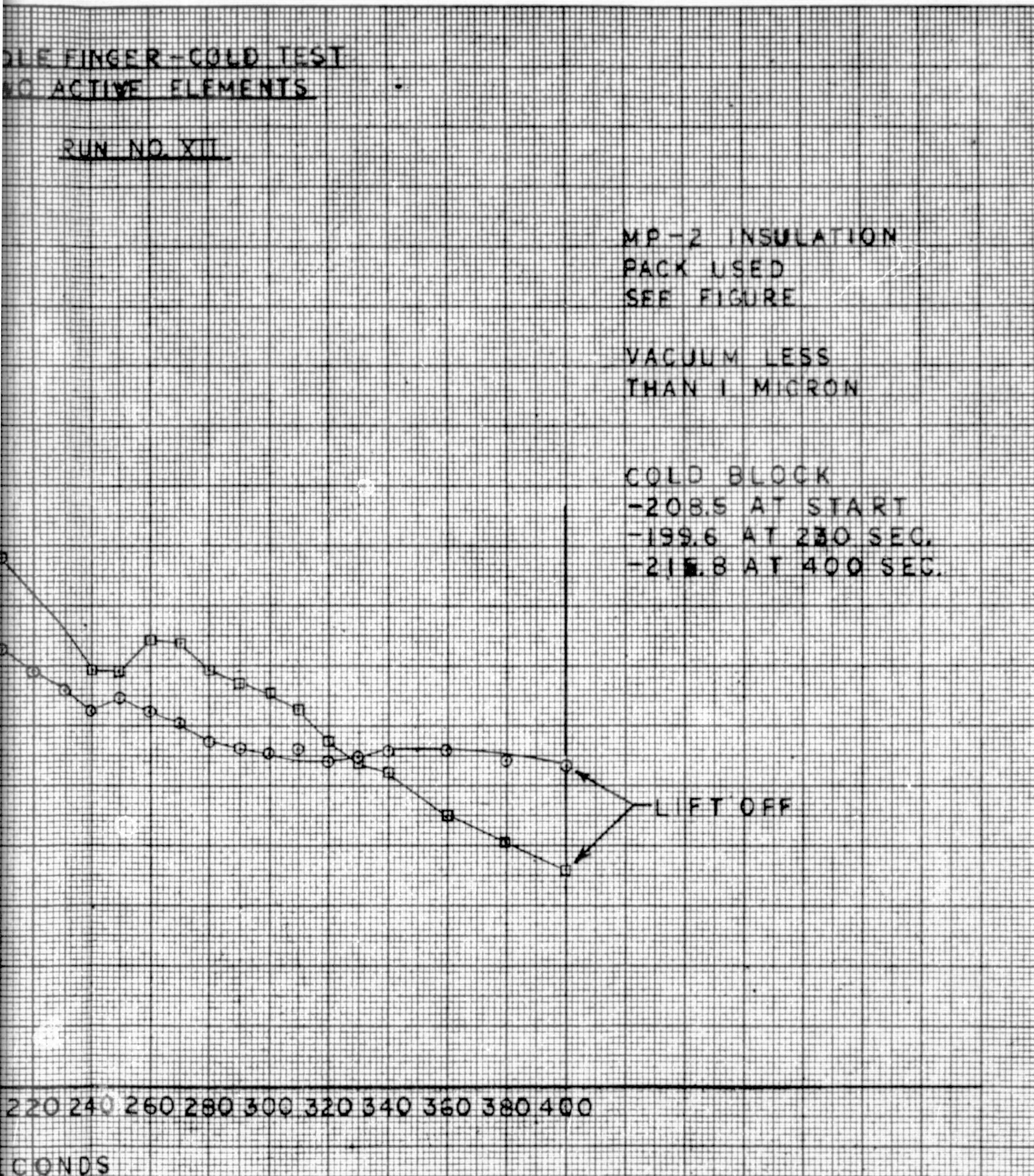
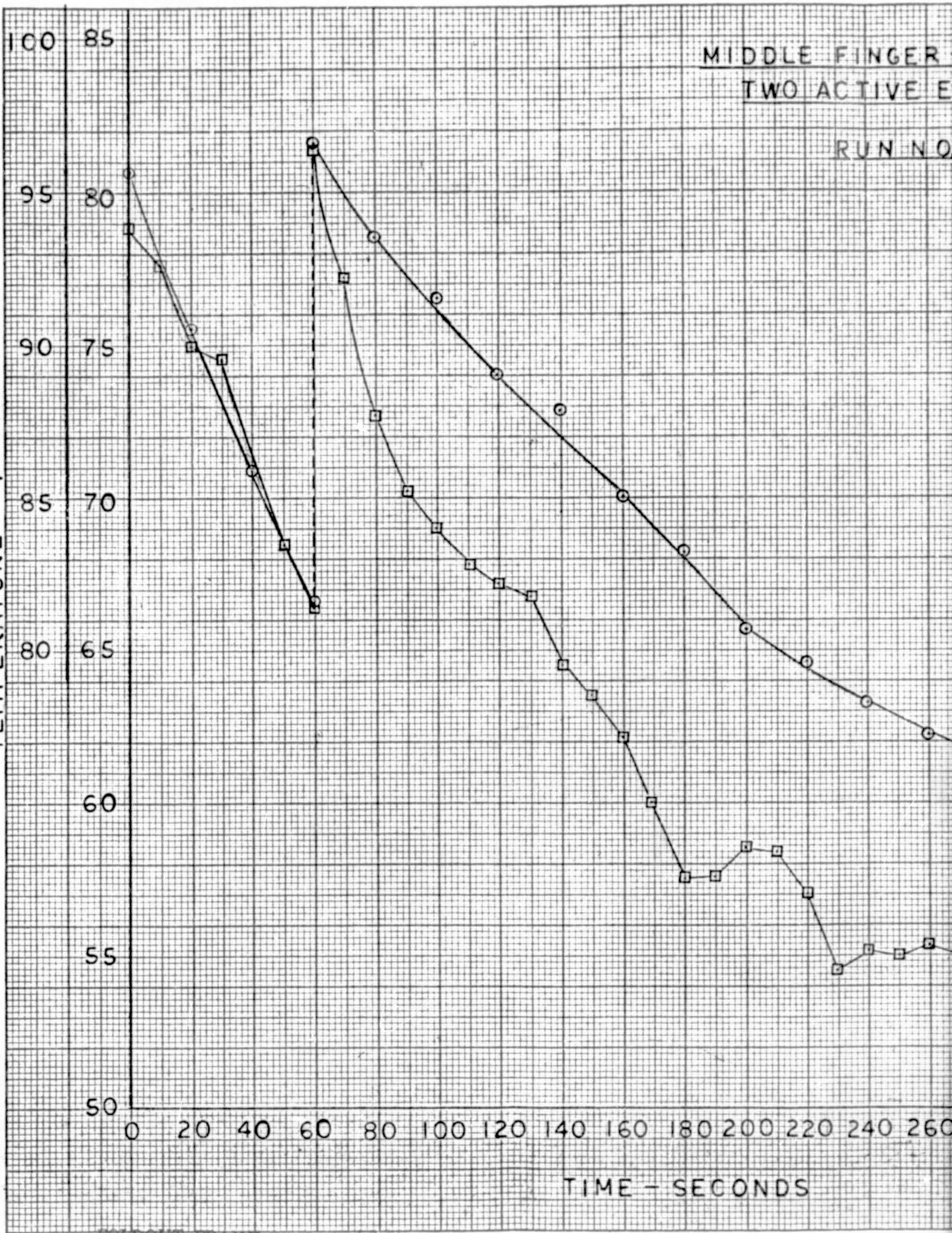

OLE FINGER - COLD TEST
NO ACTIVE ELEMENTS
RUN NO. XIII
MP-2 INSULATION
PACK USED
SEE FIGURE
VACUUM LESS
THAN 1 MICRON
COLD BLOCK
-208.5 AT START
-199.6 AT 230 SEC.
-215.8 AT 400 SEC.
LIFT OFF
220 240 260 280 300 320 340 360 380 400
CONDS

Figure 68



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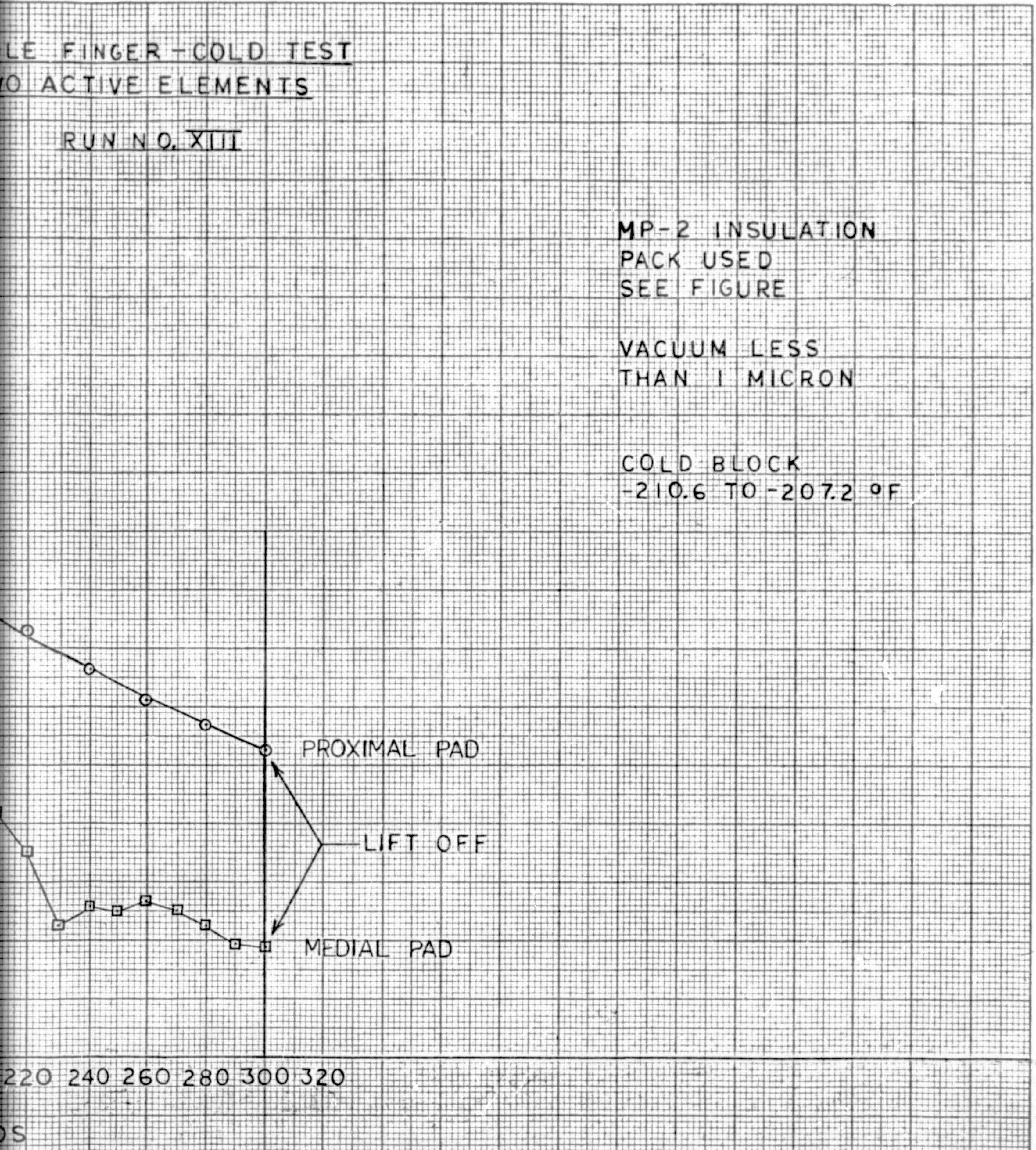

Figure 69

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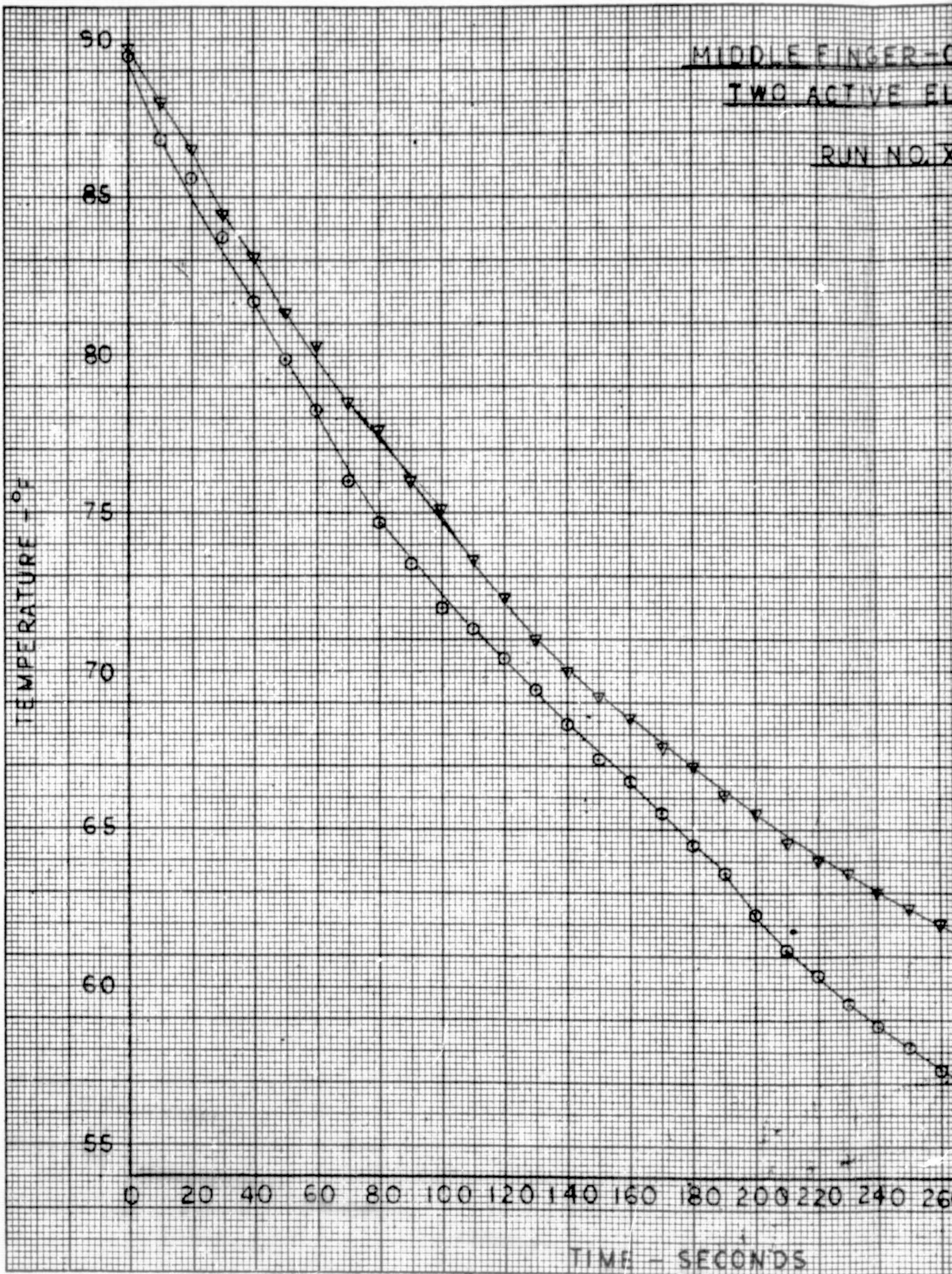
MIDDLE FINGER-C
TWO ACTIVE EL
RUN NO.X
TEMPERATURE - °F
90
85
80
75
70
65
60
55
0
20
40
60
80
100
120
140
160
180
200
220
240
26
TIME - SECONDS

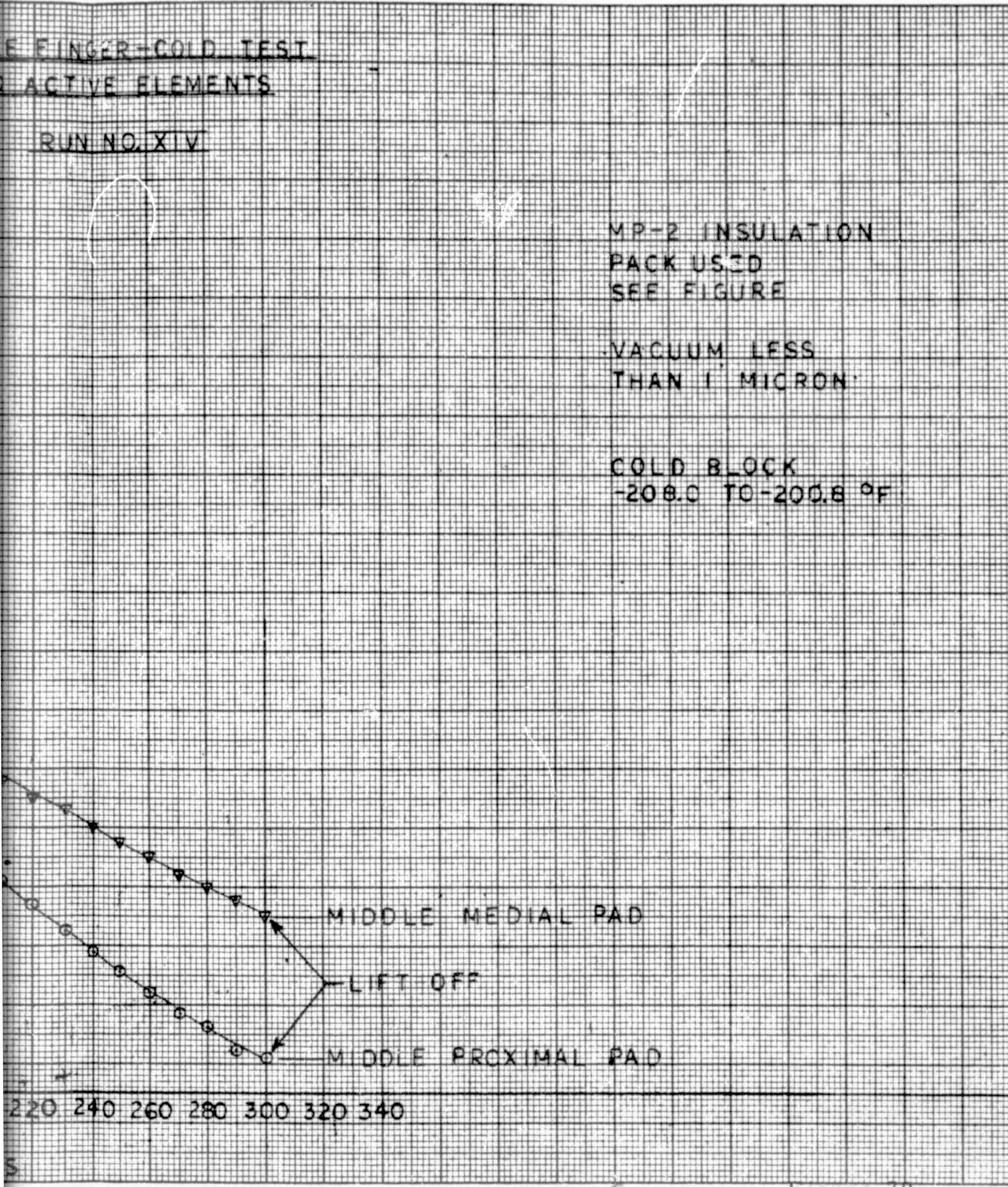

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Figure 70

DELIVERABLE AND PROTOTYPE GLOVES

Prototype Glove

The prototype glove is comprised of the ERA evaporative cooling system and the insulation pad, which were married to the Model S 3L - 106005-05 Kevlar glove (GFE). It does not have a heating system. This was designed later in the program and is incorporated in the final glove.

Work was started on the prototype glove during the fourth month and it was concluded the end of the fifth month prior to testing at Houston.

Due to the high insulation properties of the fiber-glass armor over the palm of the hand, it was found unnecessary to use the cooling system in that palm section of the hand. When pulling on a $1\frac{1}{2}$ inch diameter bar the fingers and thumb were the only pressure points ERA could define in the pressurized mode. Therefore, the fingers and thumb are the only areas where the cooling system was built into the prototype (and later the deliverable) glove. Water feed lines were passed over the back of the hand and along the sides of the finger to the wicking areas located within the insulation patches on the fingers. Figures 71 and 72 show the schematic construction of the prototype glove cooling system. The ERA cooling section of the prototype glove was made as an "over glove" section (as noted in the cross section shown in Figure 72). This was done since it was impractical, at the time, to remove the urethane bladder due to the fragility of same and the unavailability of additional (GFE) bladders.

The insulation pack, also shown in Figure 72, was based on data

PROTOTYPE HARDWARE COOLING CONFIGURATION WATER FEED LINES

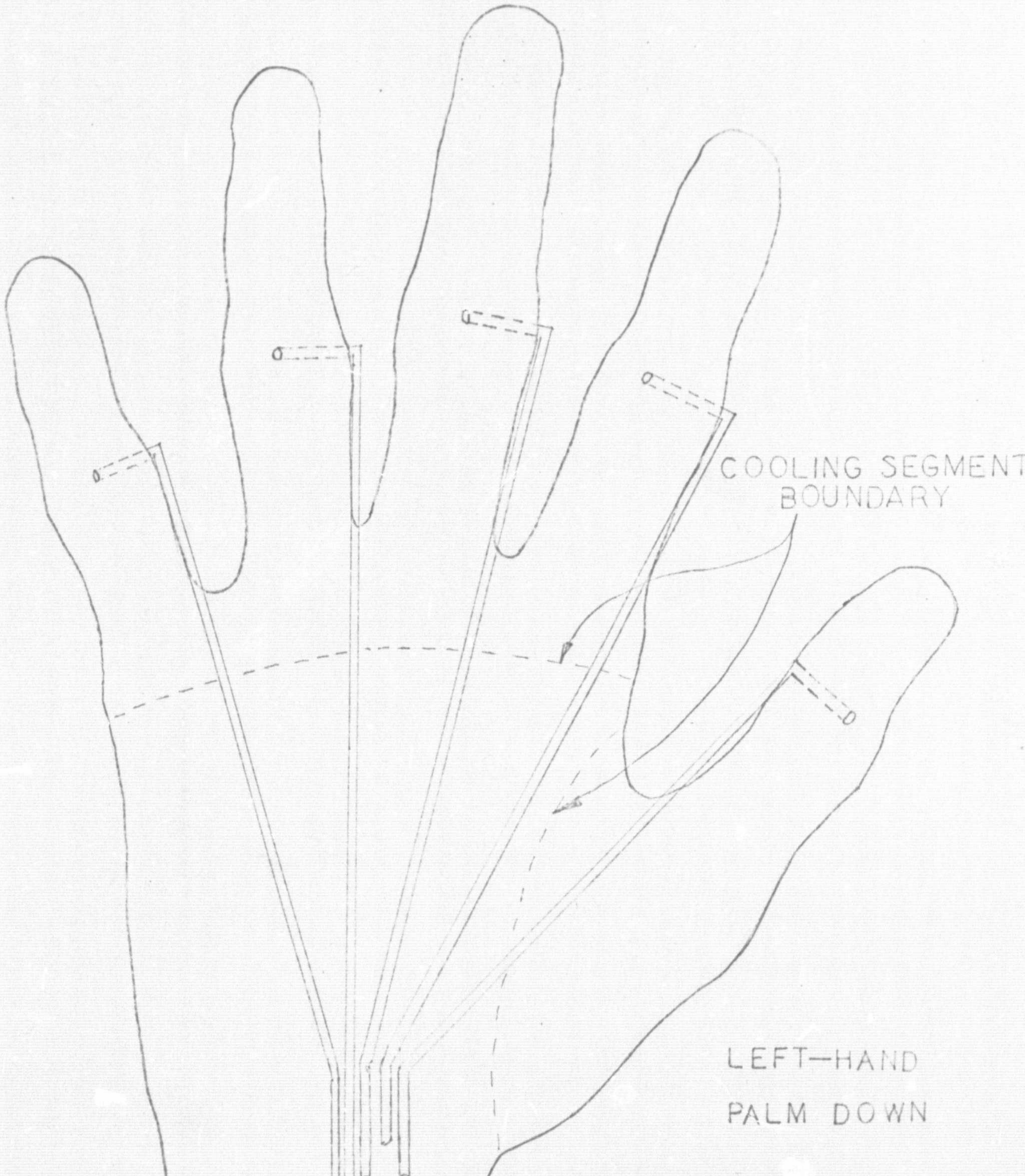

Figure 71

PROTOTYPE HARDWARE COOLING CONFIGURATION

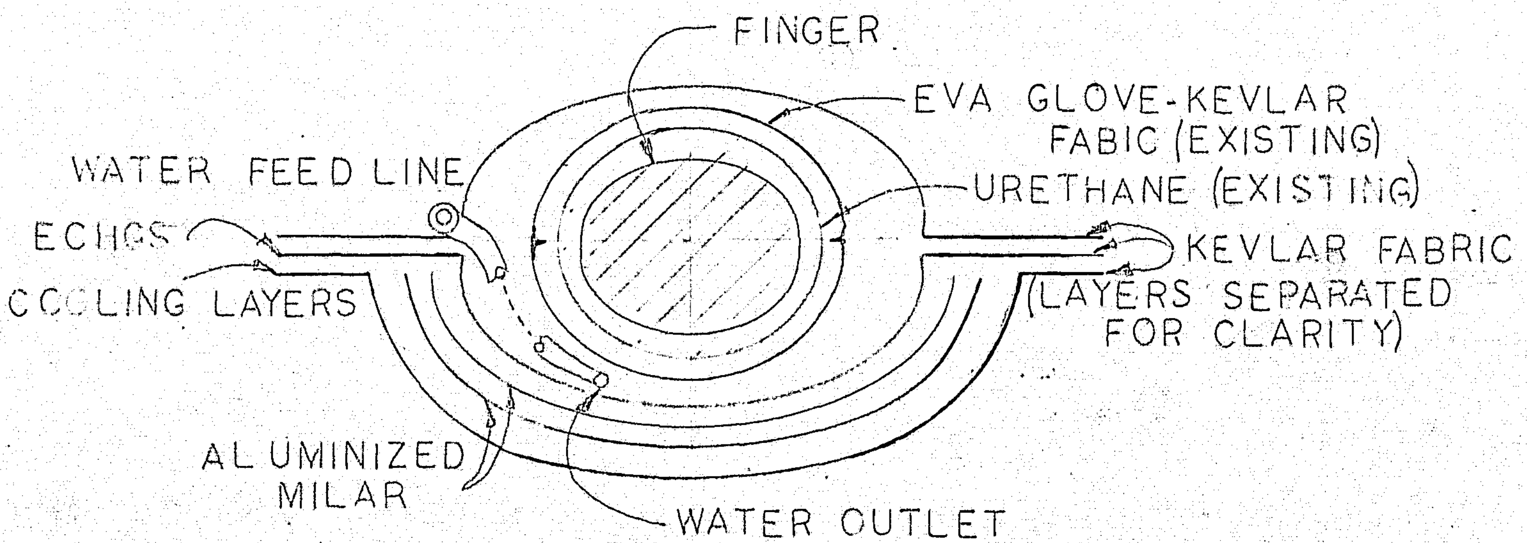

Figure 72

developed by ERA at that time. The configuration of the deliverable glove evolved further from the prototype as can be noted by comparing the two.

As designed for the initial tests the wicking consisted of two major layers of Kevlar each fully circumscribing the finger plus some wicking effect of the outside layer of the ERA prototype addition.

Tests at Houston indicated that the glove was overcooling. This was mainly due to too large a water injection rate. It also was due to the large amount of wicking. Accordingly, the deliverable glove has a finger pad only main wick plus the outer Kevlar glove which wets and also becomes a wick, dependent upon the size and the total water injection.

The laboratory water injector assembly which was supplied by ERA to provide the injected water for the prototype glove has been slightly modified to permit a controlled, lesser, water flow rate. It should be noted that this injector assembly was made to demonstrate the water cooling of the glove. It is being delivered with the final ECHGS for the same purpose, to further demonstrate the final ECHGS as desired. The injector assembly must be fully redesigned during the production development period.

Tactility

The prototype glove Model S 3L-106005-05 (GFE) was used for preliminary tactility tests under both pressurized and unpressurized conditions. These tests were run with the glove in the as received condition, only. Higher than expected "search mode" edge discrimination and less than expected dexterity were noted. ERA

constructed a "lazy-susan" with attached objects for identification. While inconclusive, the following observations may be of interest. With the unmodified glove and no pressurization, at least two persons could "feel" the threads on a 0-80 bolt, and the "hole" in a washer made by a #55 drill. A0-80 N.F. bolt has 80 threads per inch and a major diameter of 1.524 mm (0.0600 inches). A carefully drilled #55 Wire Gauge hole in hardened washer stock can approach 1.32 mm (0.052 inches). For the pressurized case, test objects large enough to be picked up with one hand could generally be identified (balls or cubes, for example).

A second "lazy-susan" was constructed and a new group of objects have been placed thereon. Brief tests with the ECHGS, unpressurized, showed that the objects on the "lazy-susan" could be identified. The 0.6 mm hole in the 3.5 mm washer could be identified as a hole without vision. The threads on the bolt were also easily identified as threads.

The "lazy-susan" is being delivered with the ECHGS for further tests at NASA as may be desired.

Evaporative Cooling/Heating Glove System (ECHGS)

General Description

The ECHGS final assembly is comprised of two major subassemblies, see Frontispiece photo, the outer (Figure 73) and the inner (Figure 74). The outer subassembly consists of the Kevlar material (GFE O.E.S. prototype S/N 001) outer element which incorporates the four finger and thumb insulation packs (Figure 76), the rubber pressure membrane (Figure 73), and the cooling water distribution system (Figure 77). The inner subassembly includes the active heating (and cooling) elements

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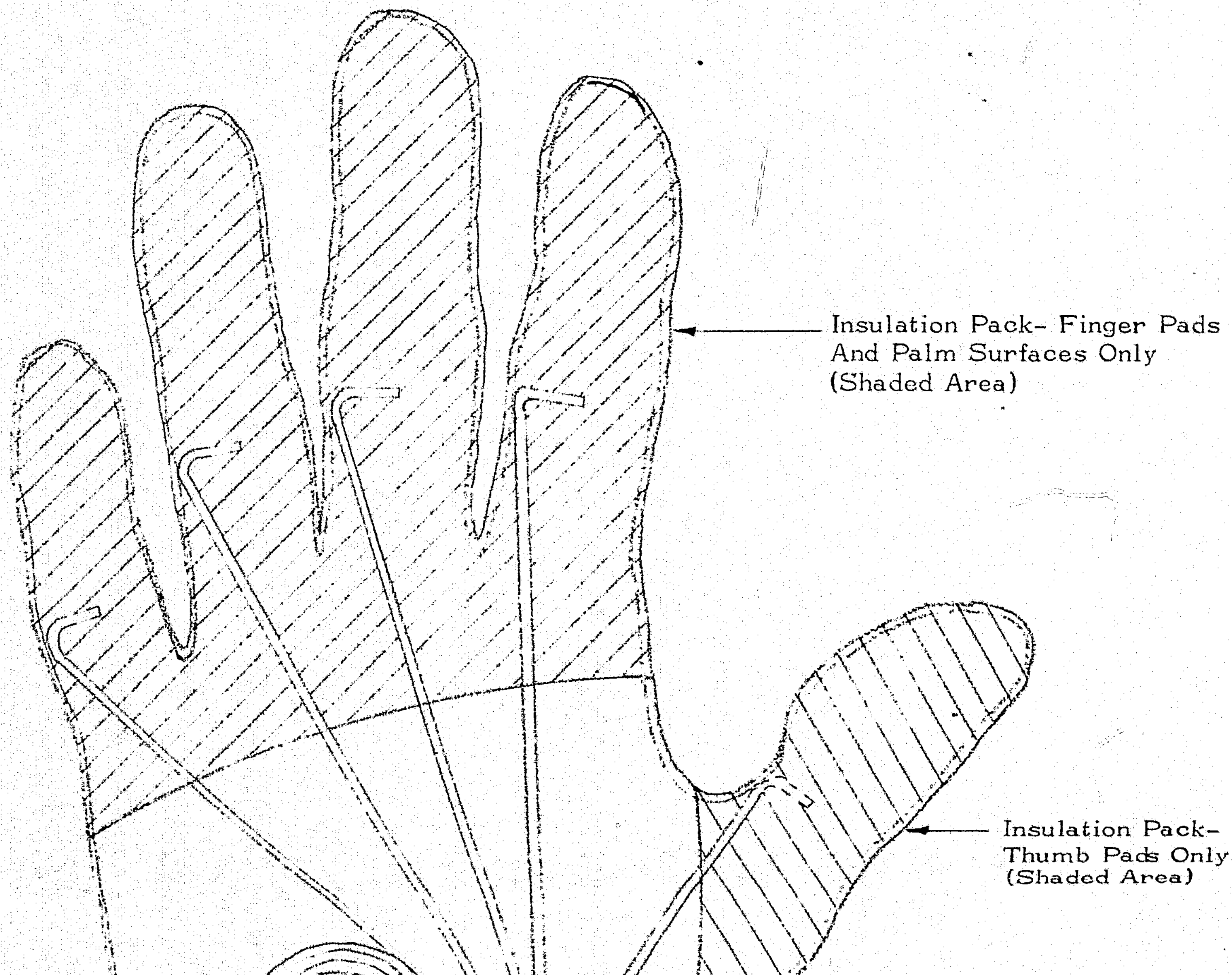
OUTER SUBASSEMBLY OF THE EVAPORATIVE COOLING/HEATING GLOVE SYSTEM (ECHGS)



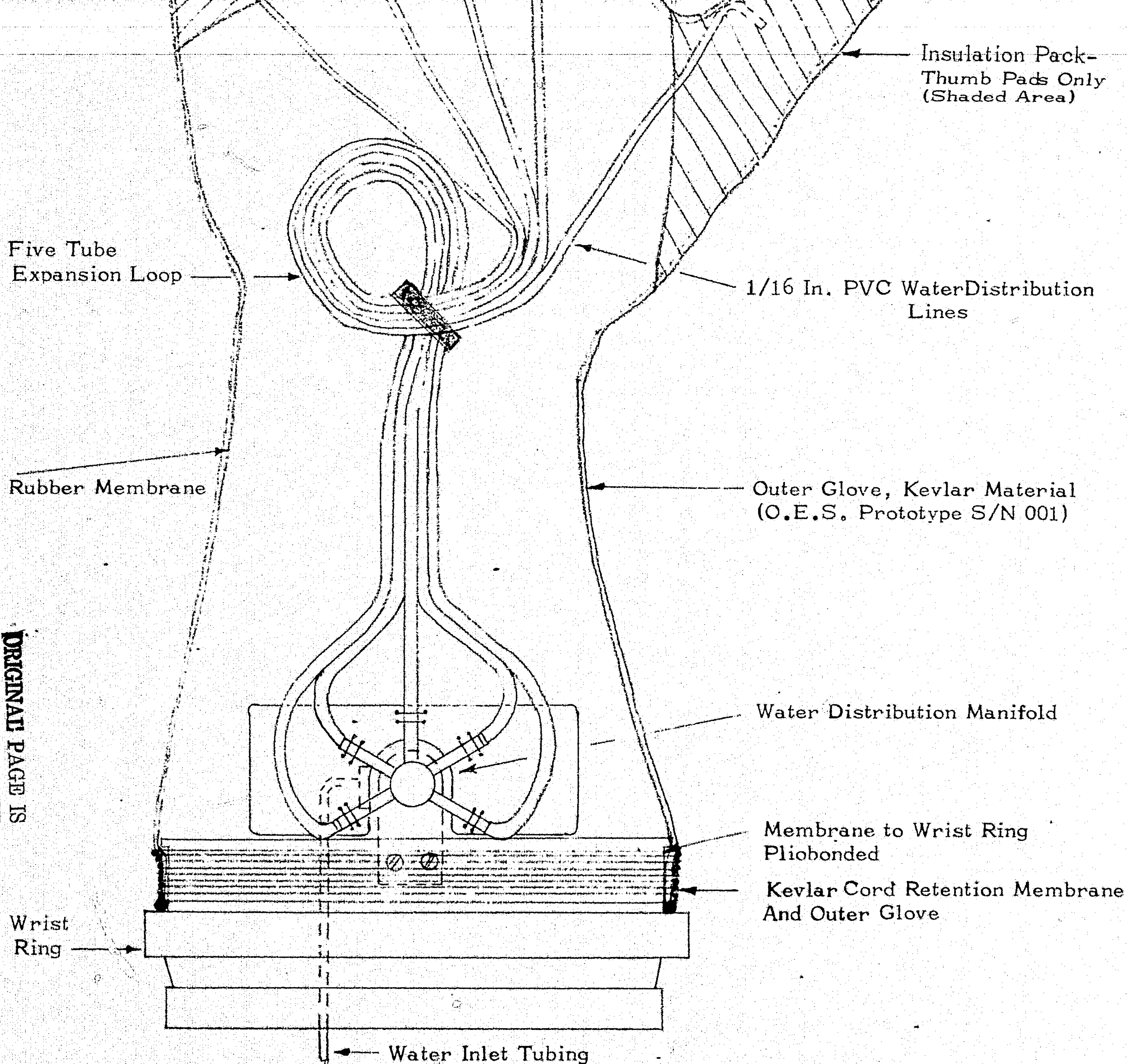


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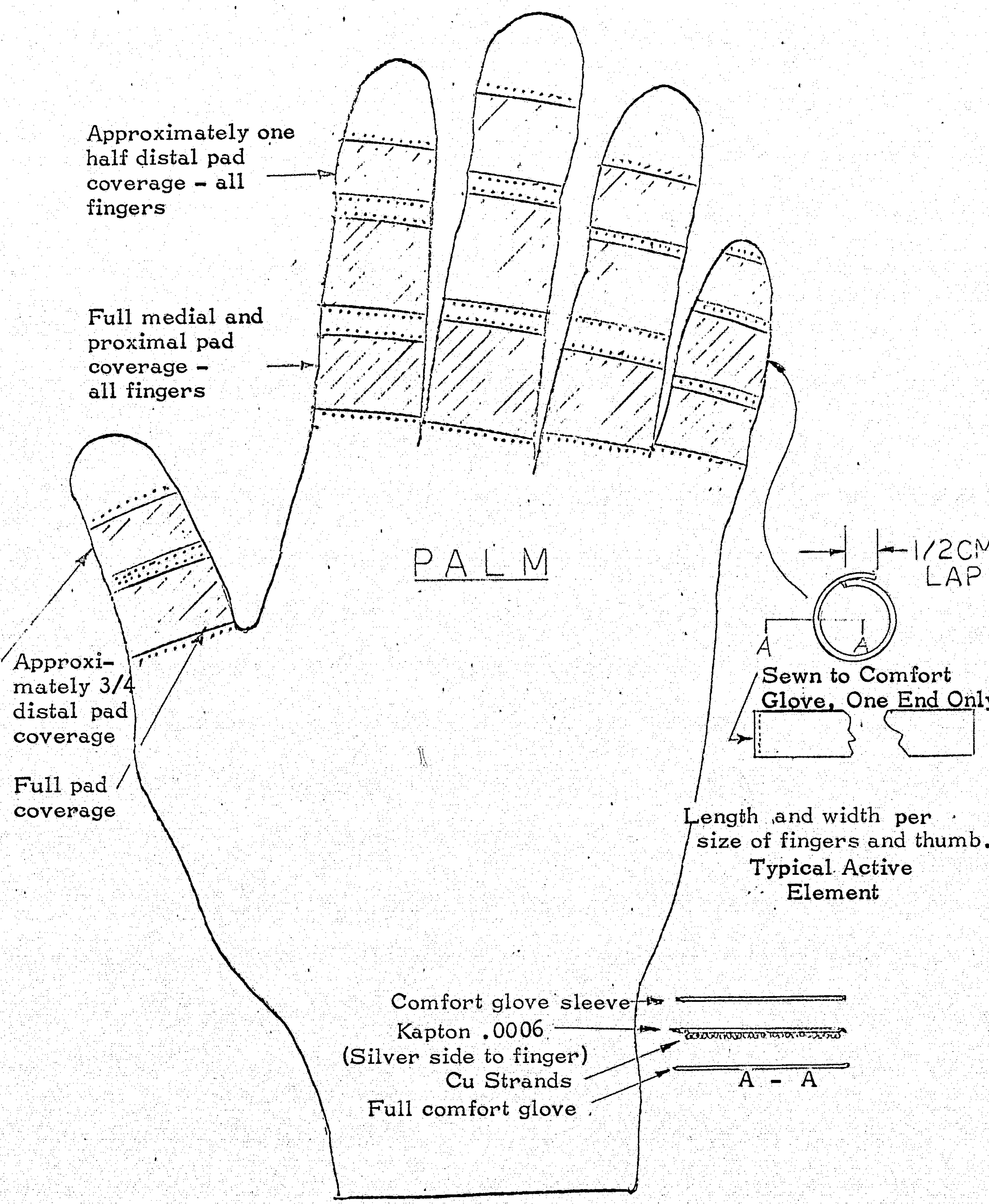
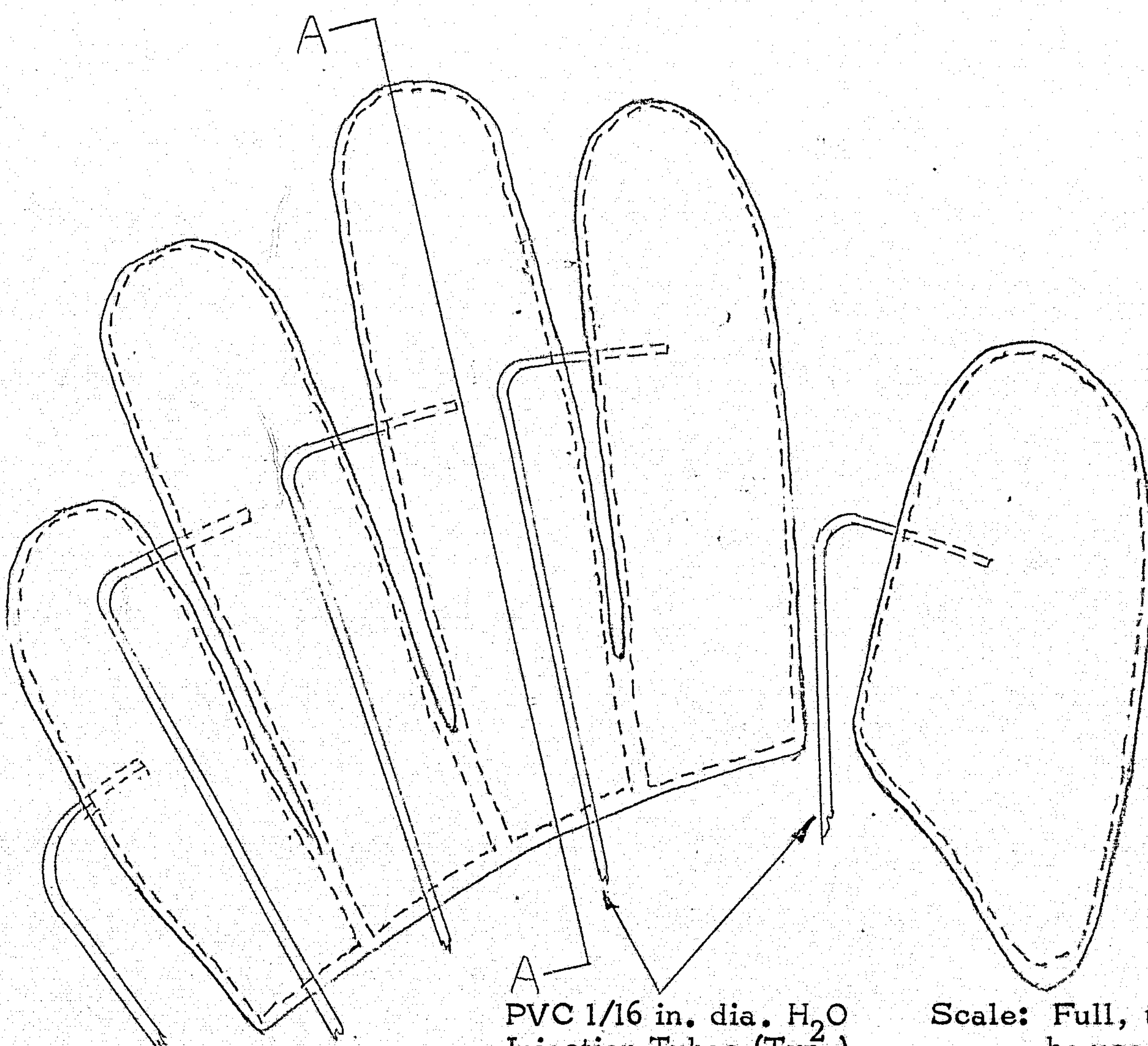
Figure 73



ACTIVE ELEMENT AND COMFORT GLOVE

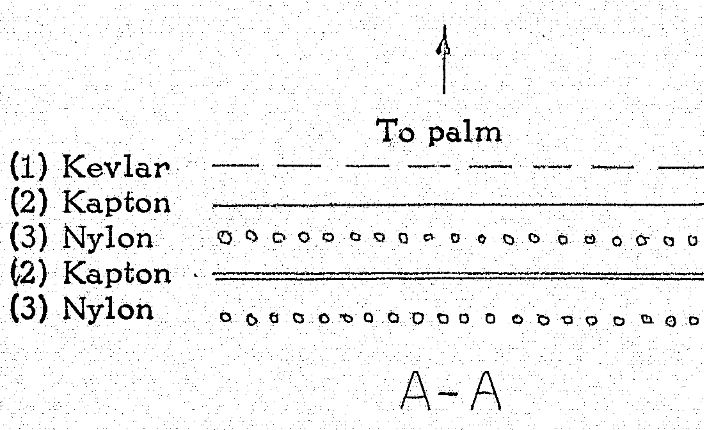
Figure 74

INSULATION PACK - FINGER AND THUMB PAD AREAS (ONLY)



Scale: Full, this can be used as a pattern

Total Area = 18.0 in^2 or 116.1 cm^2



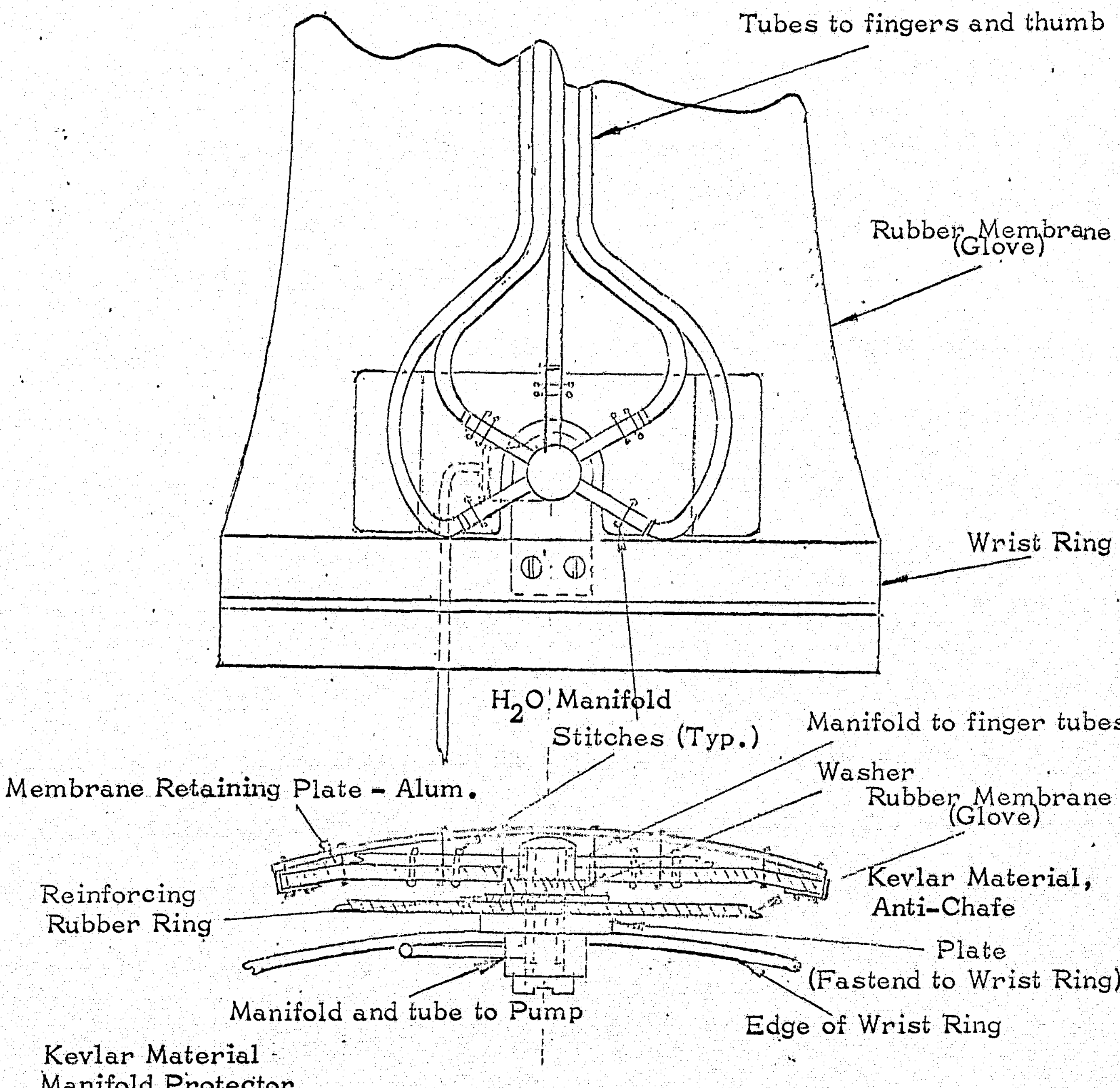
(1) Kevlar material as furnished GFE .012 in. thick

(2) Kapton material, GFE .0006 in. thick

(3) Portions of comfort glove, GFE ~ .010 in. thick

Figure 76

DETAILS OF H_2O DISTRIBUTION SYSTEM



NOT TO SCALE

Figure 77

and the comfort glove.

Function

The inner glove subassembly provides the necessary heat to prevent the fingers and thumb from becoming excessively cold when the user is working with cold materials (to -200°F). The heat is provided by conductance from the arterial - venus, capillary blood system by the circumscribing active copper elements. Full width elements are positioned at all proximal and medial finger pads. Approximately one half width elements are positioned at all distal pads. These half width pads provide thermal control for the finger tip areas normally in contact with the cold and hot work items and yet still permits good tactility for recognition checks. These same elements also absorb heat from the finger pads and conduct it to the finger blood whenever the finger pads are subjected to temperatures greater than the normal hand temperatures. The glove cooling tests, using only the active elements, showed that the heat absorption was not always sufficient when holding the required hot bar (+200°F) for three minutes. This may have been largely due to the relatively high pressures (due to the material outgassing at the high temperatures) which reduced the effectivness of the test insulation pack. The active elements, alone, can provide adequate heat reduction for intermediate temperature levels and time exposures.

However, for an adequate safety margin, the evaporative cooling system, developed during the first part of the program, was installed in the deliverable ECHGS. This system provides water to each finger between the proximal and medial pads, at the Kevlar layer of the insulation pad. This layer and the outer Kevlar glove became wicks

for the cooling water. The direct evaporation to space(or simulative space vacuum in the laboratory) provides cooling in proportion to the amount of water injected. The cooling by this method, as supplied under the current contract, is not controlled by direct temperature sensors and is not variable over various parts of the hand, since that sophistication is beyond the converage of this contract. The required cooling will vary in accordance with the amount of hand heating due to the area in contact with the hot body, the hot body temperature and the local pressure on the finger pads. A method of water injection control in relationship to these variables will be developed during the pre-production development period.

The finger and thumb insulation packs were designed to provide an adequate thermal barrier to permit the active heating and cooling units to perform satisfactorily within the finger comfort range. A maximum of flexibility was obtained by keeping the width of the finger sections the same as the plan form of the outer Kevlar glove. Thus the "three dimensional" stiffening effect was avoided. The entire finger length and approximately three fourths of an inch (or 19 mm) of the palm length were covered in one insulation pack. The palm area is covered just forward of the steel pressure holding member in the palm of the O.E.S. S/N 001 Kevlar (outer) glove. This will protect against random contact of the palm with the cold or hot work items. The thumb was covered by a second insulation pack. The thumb pad is designed to protect the thumb against low and high temperatures during the many positions the thumb will assume while work is accomplished. Therefore, the pad is wider than the finger pads and it slightly circumscribes both sides from the pad areas. Also the heel of the hand is partially protected at the beginning of the thumb.

The rubber membrane was made from a standard rubber glove. The area where the water manifold penetrated from the inside of the glove to the vacuum or space side of the glove was reinforced with rubber membrane. The wrist ring attachment point was also reinforced. This pressure membrane seals the space suit pressure from space. The pressure load is carried by the Kevlar outer glove and the integrated load carrying steel and Kevlar reinforced areas thereof. The use of rubber is considered an interim measure by ERA since the higher strength of urethane, and therefore the use of thinner material, will permit a measure of improved glove tactility. Future programs should include the use of molded-to-fit urethane membranes.

The outer Kevlar glove (GFE) provides the support for the pressure membrane, as noted above, acts at times as part of the wicking surface for the evaporative cooling, provides containment for all elements of the ECHGS and provides for wear resistance and a frictional element for the work.

The wrist ring (GFE) supports the rubber membrane and is bonded to same by the use of Pliobond # 20 (MIL-A 81270) adhesive. The outer Kevlar glove and concurrently the rubber membrane are retained at the wrist ring by a single layer of heavy Kevlar cord (the same cord with which the GFE glove was supplied to ERA, Figure 73). The cord positioning is further assured by a coating of Pliobond adhesive. The glove tensile load, due to pressurization, is carried by the two side plates fastened to the wrist ring. These are the same parts which came with the glove assembly supplied to ERA. A Kevlar skirt, retained to the glove assembly by two draw strings, was added by ERA to protect the metal side plates and the Kevlar

cord as well as to provide an improved neatness.

The ECHGS identification is located on a Kevlar material panel bonded to the inside of the wrist ring.

Inner Glove Assembly-Design Details

The inner glove assembly is made specifically for the user (or a person with a very similarly sized hand and finger pad and flexural areas). The left hand unit, delivered under this contract, has been made for one of the two people having the smallest hands among the Environmental Research Associates personnel. The reason for this is that the NASA supplied outer, Kevlar glove was a small size. The necessary additions to make the ECHGS require the use of a small hand.

Figure 75 shows the finger and thumb areas and provides a fairly good idea of the pad and flexural area lengths. Table 4 provides the sizes of the finger and thumb pads. These hand dimensions should be duplicated as closely as possible by any test subject to insure good heat transfer. The best heat transfer from the entire circumference of the finger to the pad areas is obtained by the controlled light pressure of the active elements on the fingers. Thus the need for fitting the inner glove to the user's hand.

The active heating (and cooling) elements of the inner glove, consist of fine, highly flexible copper conductors affixed to a .0006 inch thick chromium and gold plated strip of Kapton. The Kapton acts as a radiation heat loss barrier and as a support for the copper strands. The strands are laid parallel to one another and affixed

Dimensions of Design Subject's
Fingers (Left Hand)- Millimeters

Finger	Finger Pad					
	Proximal		Medial		Distal	
	Circumference	Length	Circumference	Length	Circumference	Length
Index	72	21 (at center)	62	14	58	24
Middle	74	19	65	18	59	28
Ring	68	19	58	18	51	25
Small	60	17 (at center)	52	13	49	22
Thumb			70	17	68	33

HAND PRINT OF SUBJECT
USED FOR FINAL GLOVE PATTERNS

Note: Lengths of fingers and finger pads, width of hand properly shown herein. For full finger size data see Table 2.

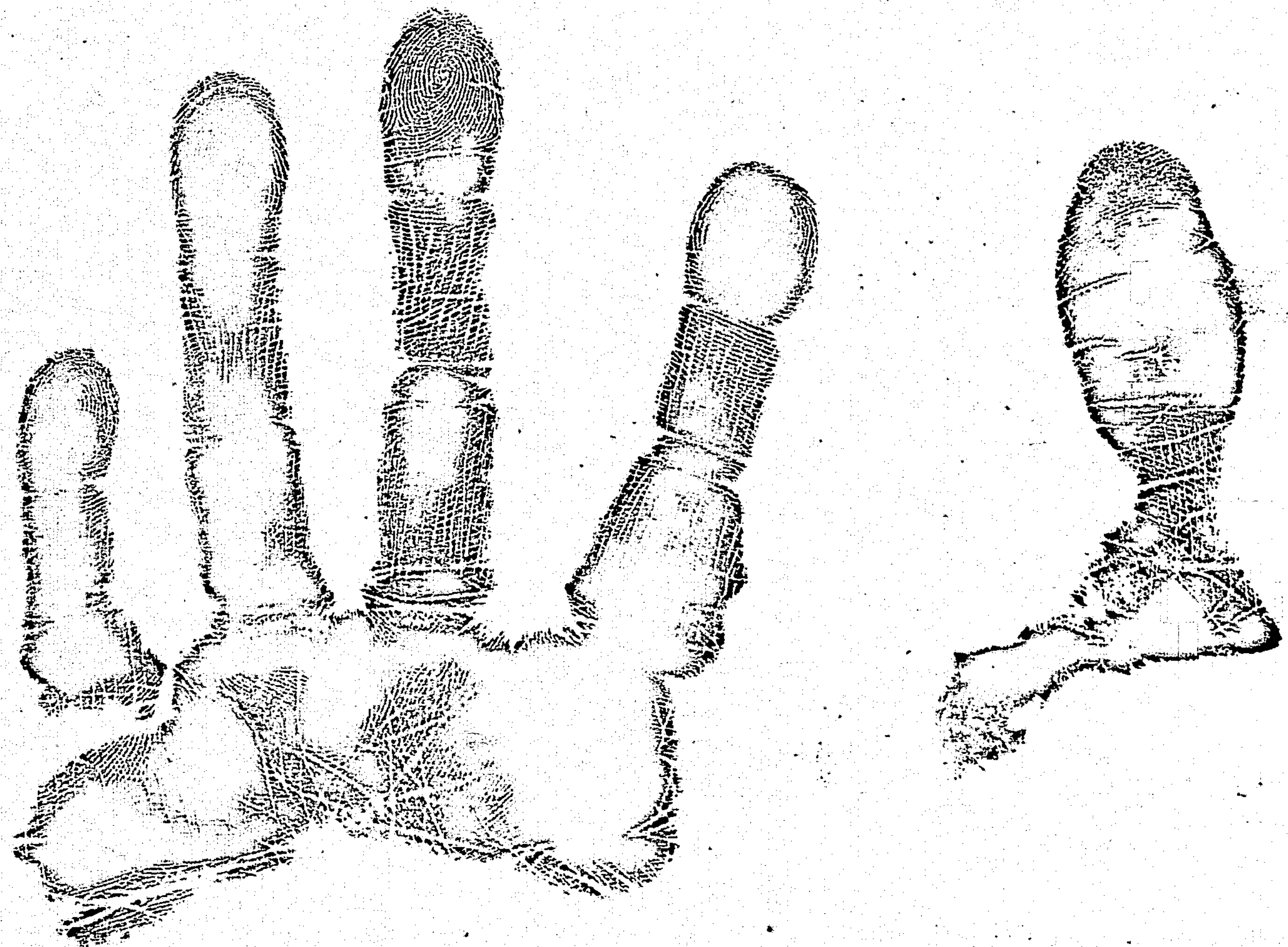


Figure 75

to the Kapton at four transverse line areas by the use of Pliobond adhesive. Each active element is sewn transversely, on the top of the finger pad for which the element was dimensioned. The element is wrapped around the finger until it overlaps itself one centimeter. Each element is then further affixed to the comfort glove by sewing, pre-hemmed and predimensioned, comfort glove finger sections (from a second glove) so that each active element is positioned at the corresponding finger pad on the subject. The element is then positioned to the finger pad and adjacent area around the finger but can slide circumferentially as the finger is flexed. The comfort glove material outer guide exerts a mild pressure on the active element to insure good contact with the finger for good heat transfer. Unfortunately, the last set of comfort gloves received from NASA were very short, thus it was necessary to add a cuff section to make it a standard long glove. The specific sizes of the elements and the individual weight is provided in Table 5.

Outer Glove Assembly

The insulation packs (four fingers plus a short palm section in one and a thumb section only in the other), Figure 76 consist of five layers sewn together with Kevlar thread. The layer nearest the finger is Kevlar cloth (the same as that used on the GFE outer glove) next is a .0006 inch thick metalized Kapton radiation shielding layer with the silver side to the finger, the third layer is comfort glove material which acts as a spacer between the Kapton layers, the fourth layer is a second radiation barrier of Kapton and the fifth is another layer of comfort glove to protect the Kapton from the Kevlar material of the outer glove. The overall thickness is approximately .031 inches. The comfort glove and Kevlar materials

ACTIVE HEATING (AND COOLING) ELEMENT DIMENSIONS

Finger	Proximal Pad		Medial Pad		Distal Pad	
	Size MM	Wt. Grams	Size MM	Wt. Grams	Size MM	Wt. Grams
Index	18 x 76	2.58	15 x 66	1.86	11 x 70	.99
Middle	20 x 74	2.79	20 x 68	2.56	13 x 70	1.17
Ring	18 x 68.5	2.32	17 x 60	1.92	11 x 67	.95
Small	15 x 62	1.75	13 x 54	1.32	10 x 60	.77
Thumb			17 x 73	2.34	18 x 81	2.58

Total wt. of all active pads 25.90 gms.

Total area of all active pads 147.99 cm^2

Table 5

permit good flexibility of the pads. The insulation pack is sewn through the Kevlar (GFE) glove with a hand stitch. In the production glove the packs would be sewn to the finger pad sections of the glove before the glove components are sewn together thus eliminating the need for "through" sewing and thereby providing full protection for the insulation pack attaching threads.

The 1/16 inch diameter polyvinyl chloride water distribution tubing terminates at the medial pad of each finger and thumb. The tubing is sewn with Kevlar thread to the insulation pad at the terminals and to the backside of the glove as the tubing traverses the glove from the water manifold at the wrist ring area. The five tubes are Herco solvent bonded to one another, in a flat pack, and a 360° loop is provided by tying the pack at the cross over point with a loose tie of Kevlar cloth. This loop permits hand flexure and assembly of the rubber membrane to the Kevlar outer glove without strain on the PVC tubing.

The water penetration from the inside of the astronaut suit to the finger areas is accomplished at the wrist ring by the use of Clippard Minimatic fittings (Clippard Instrument Laboratory, Inc., Cincinnati, Ohio) mounted to a brass plate support which in turn is supported by the wrist ring by two number 2-56 flat head screws (figure 77). The use of Clippard part No. 15002-1 adjustable "L" fitting and a simple threaded manifold permits screw thread attachment through the doubly reinforced rubber membrane. The water inlet to the assembly is affected by use of connecting 1/8 inch diameter tygon tubing from the water injector through a Clippard 90° elbow tube to a machine thread fitting. Sealing was effected by soldering and epoxying. The adjustable Clippard fitting incorporates an "O" ring seal at the head end of the attaching hollow bolt. The water passes through the hollow bolt from the Clippard

fitting to the manifold. The use of these standard fittings make replacement easier if it is ever required. However, production gloves would incorporate anodized aluminum parts of similar construction. The five-way outlet manifold would have axially positioned parallel outlets. Fusion joints would be eliminated by integral machining wherever possible.

The entire water manifold, being mounted on top of the rubber membrane had to be shielded from the membrane so that upon pressurization the membrane would not expand into the manifold with possible resulting chafing and failure. A 1/16 inch aluminum plate essentially bent to conform to the wrist ring O.D., was covered on the edges with Kevlar cloth by sewing through holes in the plate. The outer Kevlar glove is protected from the manifold by the placement of a piece of Kevlar cloth over the top of the manifold. The cloth is retained by Kevlar threads sewn through holes in the aluminum shield.

The rubber membrane is retained to the wrist ring by use of Pliobond #20 adhesive plus the overwrap of Kevlar heavy duty cord, Figure 77a. A double Kevlar thread was bonded over an approximate 1/4 inch diameter to the tip of each finger and to the thumb by use of Pliobond adhesive. These threads were left long so that needles could be used to pass through the tips of the Kevlar glove without requiring the rubber membrane to be within the outer glove while the needles were passed through. The threads were then sewn (loosely) with a locking stitch and all threads were pulled through as the membrane was positioned within the outer glove. The locking stitches were pulled tight and the ends were tied off and spotted with Pliobond. This finger tip retention method was also used during the full glove tests. Care should always be taken when donning and especially removing the hand from the ECHGS outer

GLOVE TO WRIST RING ASSEMBLY

METHOD

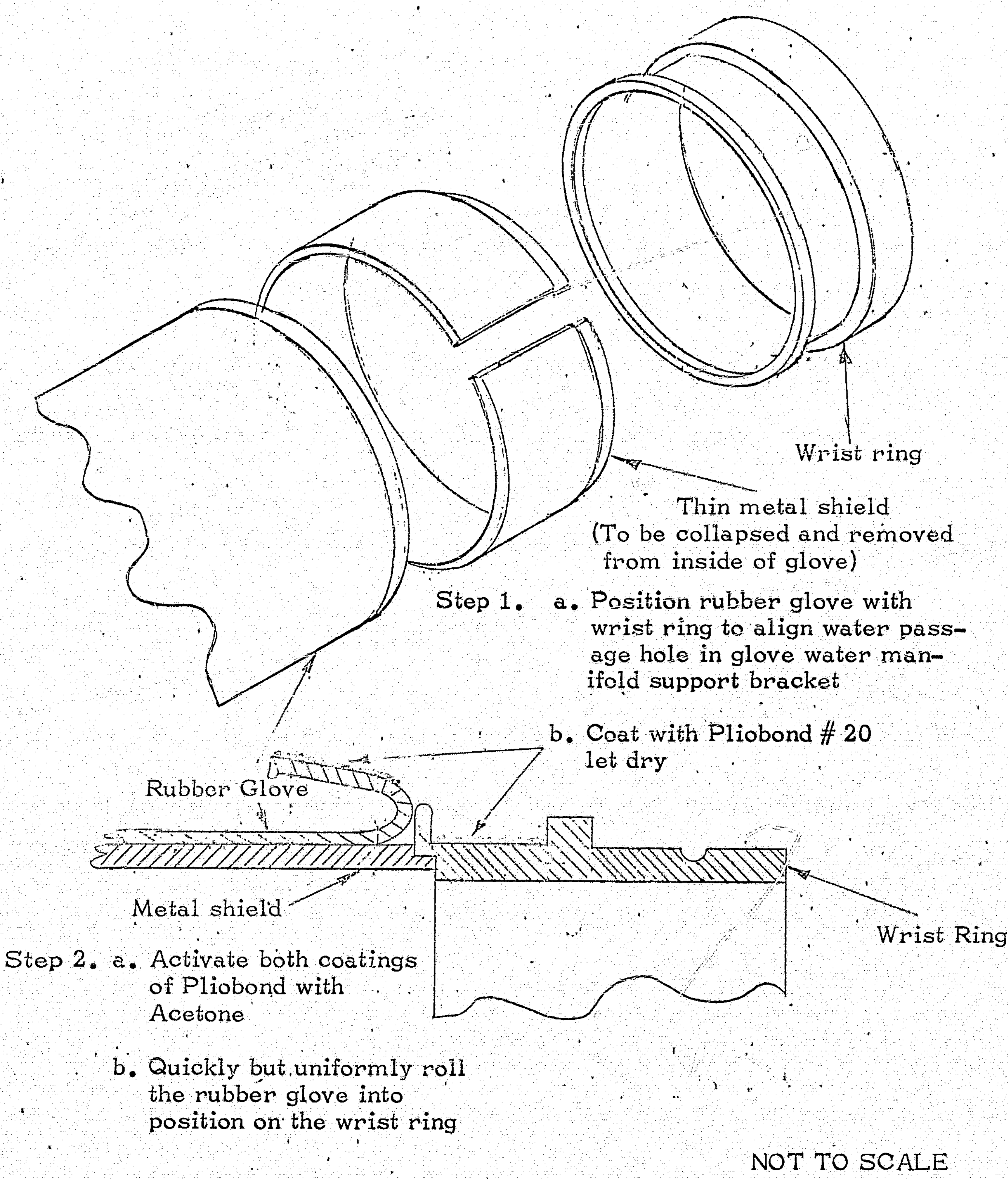


Figure 77a

glove assembly. Tips of the membrane should be grasped through the outer glove with another hand, as the fingers are moved out of the glove. The motion should be by one finger at a time; thumb to little, then little to thumb, etc., until the fingers are free from the glove. On donning the gloves, the use of significant amounts of body powder inside the rubber membrane and/or on the comfort glove will help in preventing the hand from sticking in the membrane. In the production glove, the molded urethane bladder would have "tabs" at the end of each finger to firmly affix it. Also, all glove components would be sized to individual measurements. Donning of the glove would be easily accomplished.

Materials

The materials used throughout the ECHGS include only previously approved materials with the possible exception of the polyvinyl chloride and tygon tubing for the water system and the rubber pressure membrane. This tubing could be made of different materials, such as urethane, in the production gloves, if necessary. The pressure membrane will be made of urethane in the production glove, thus eliminating the rubber. The material used included Kevlar material, Kevlar thread, additional comfort glove material (as supplied by NASA), copper, aluminum, brass, and Kapton. The use of rubber (modified rubber glove) for the pressure membrane was approved by NASA for this program after an extreme leakage was encountered with the NASA supplied urethane material pressure membrane and it was determined that a new unit would not be procurable in time for this program.

Acceptance Tests

The ECHGS S/N 001 acceptance tests included the following:

1. Pressure check of the water injection distribution system to 40 psi. No leakage after one half hour at pressure. A flow check of the water injection system showed all tubes to be open and proper wicking occurred at each finger and at the thumb.

2. Pressure bladder leakage check (without restraint) at 4 inches of water pressure. An initial leak at the wrist ring retention was sealed by coating with Pliobond adhesive. No measurable leakage was noted during a subsequent half hour hold at pressure.

3. Pressure bladder leakage check (with the outer Kevlar glove restraint) was made at 4 psig with the glove at sea level atmospheric pressure. The leakage was measured by a Hastings Mass Flowmeter, model LF-D5, with a range of 0 to 5 standard cubic centimeters of air per minute. Model LF-D5 Hastings Mass Flow Transducer was used in conjunction with the Flowmeter. Pressure was measured by a Barton Instrument Corp. pressure gage in inches of water (110.77 inches of water = 4.0 psi). Leakage was measured both with and without the glove assembly in the pressurizing and flow measuring circuit. There was a very small leak in the system, without the glove, thus subtracting this value from the total provides the glove leakage.

Pressure - 4.0 psig	Leakage-Standard Cubic Centimeters
Leakage - Pressurizing and Flow Measuring System Plus the Glove Assembly	1.7
Leakage - Glove As embly as attached to the astronaut's suit wrist ring and an "O" ring sealed ERA adapter to same	0.7

The leakage was monitored continuously for eight hours with pressures varying from about 2.0 psig to 4.0 psig. No increase in leakage was noted during this period.

4. Weight

Inner Glove Assembly		37.3 grams
Outer Glove Assembly (With Glove Side of the Wrist Ring)		251.9 grams
	Total ECHGS	289.2 grams
	or	.638 pounds

5. Comfort

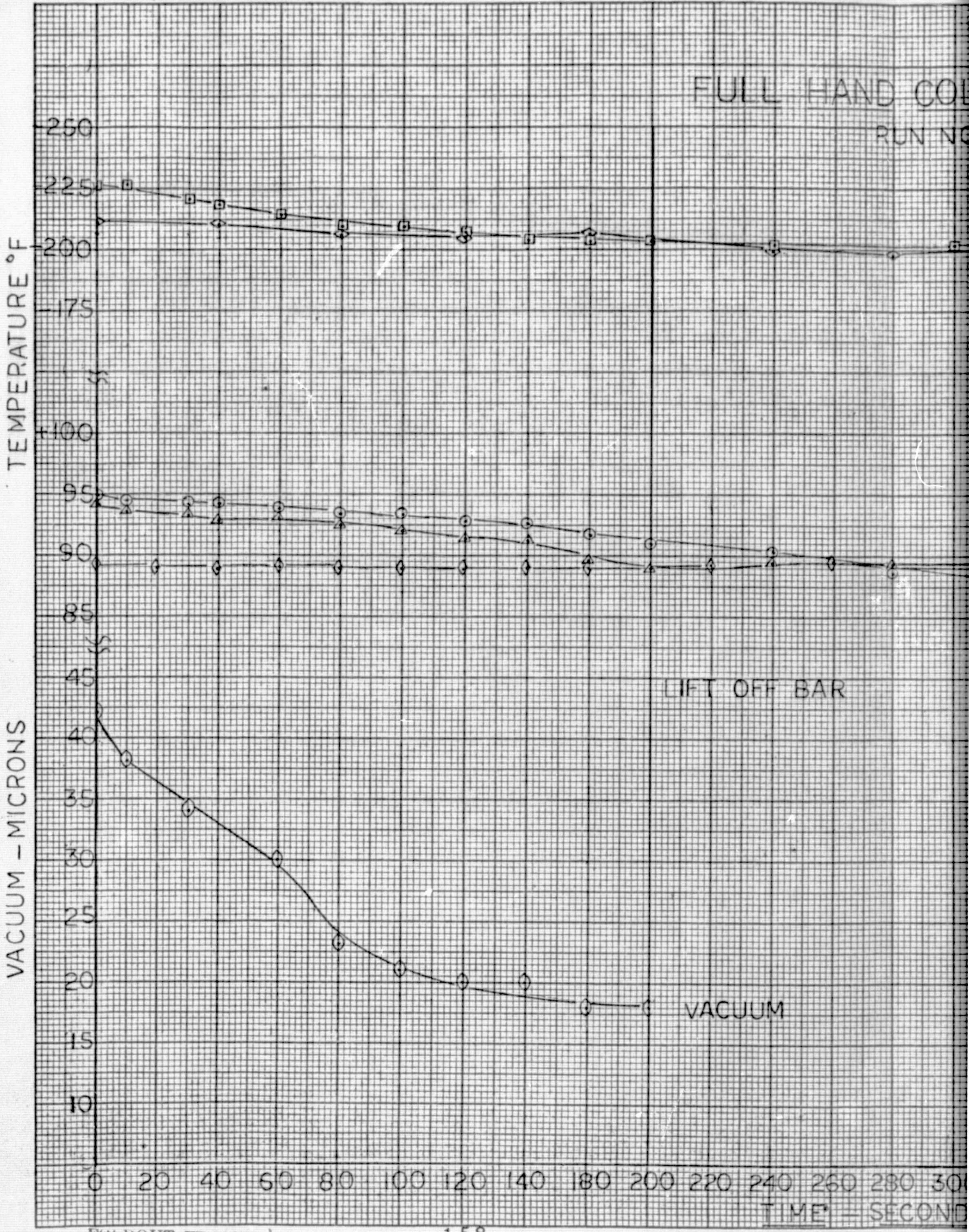
The glove is comfortable to the subject for which the inner glove was designed and fabricated. The outer (GFE) glove is on the small side to contain the necessary ECHGS elements. Full finger flexibility is afforded. Tactility tests and flexure tests were very limited but were deemed satisfactory.

6. Cold Bar Tests

Three full hand tests were made using a $1\frac{1}{2}$ inch diameter aluminum cold bar at -200° F or colder. These tests are presented in Figures 78 through 80.

These tests were run using a $1\frac{1}{2}$ inch diameter by 18 inches long bar which was insulated at each end. The bar is instrumented at the center and one end with Resistance Temperature Determination (RTD) temperature sensors. The center (hand hold area) of the box was equipped with a removable panel which permitted cooling of the bar by immersion in liquid nitrogen. (See Figure 81) In use, the bar was cooled so that the end temperature was subcooled, to about -240° F and the center temperature was then allowed to warm to the starting temperature. The colder ends then acted as heat sinks absorbing the input to the bar from the glove.

The twelve pound pull on the bar was measured by a fish scale attached to the wall, Figure 81. Test no. 1 (Figure 78) was made using two active elements per finger (proximal and medial pads) and one active element on the thumb (proximal/medial, a combined pad on the subject's hand).



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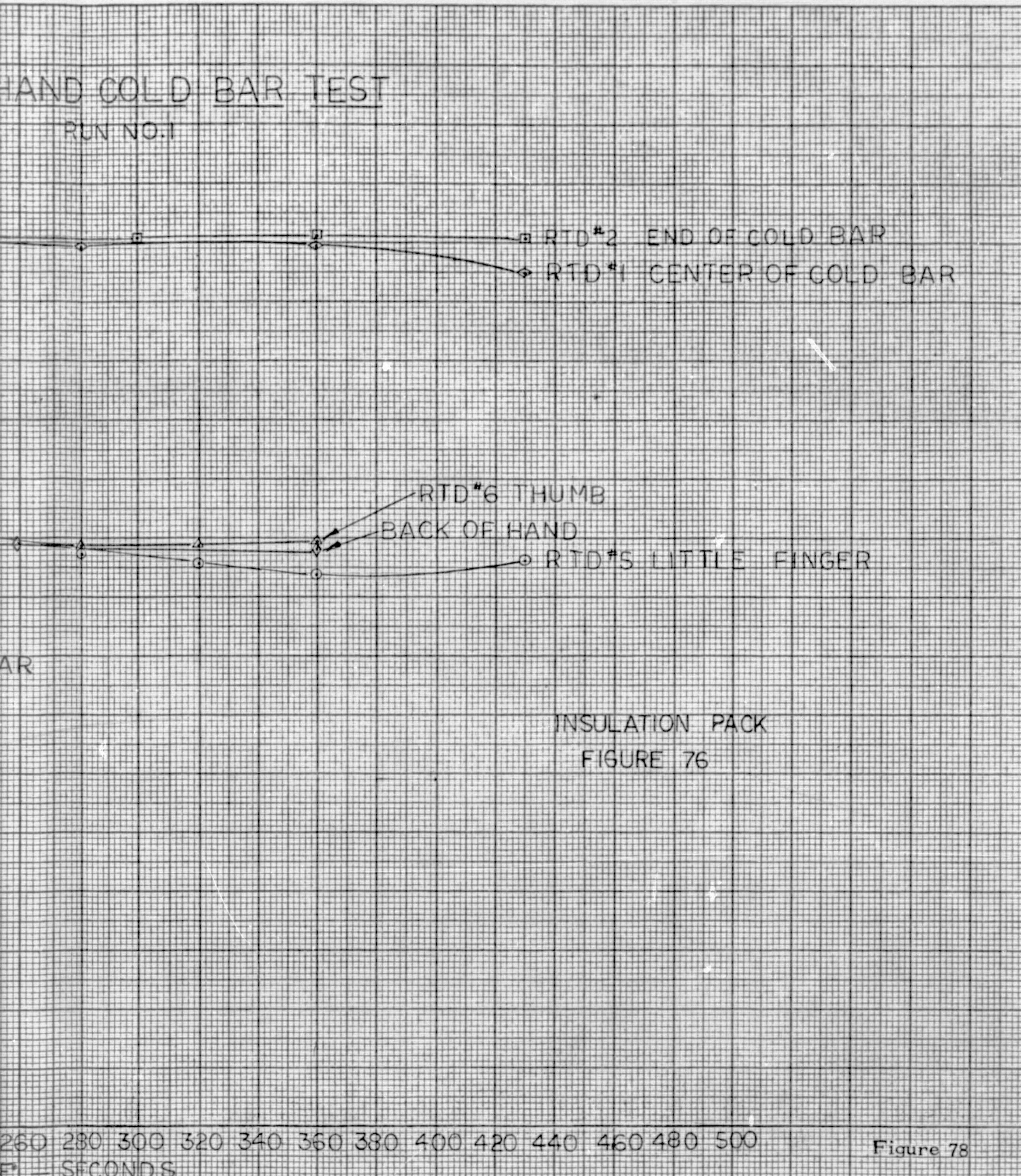
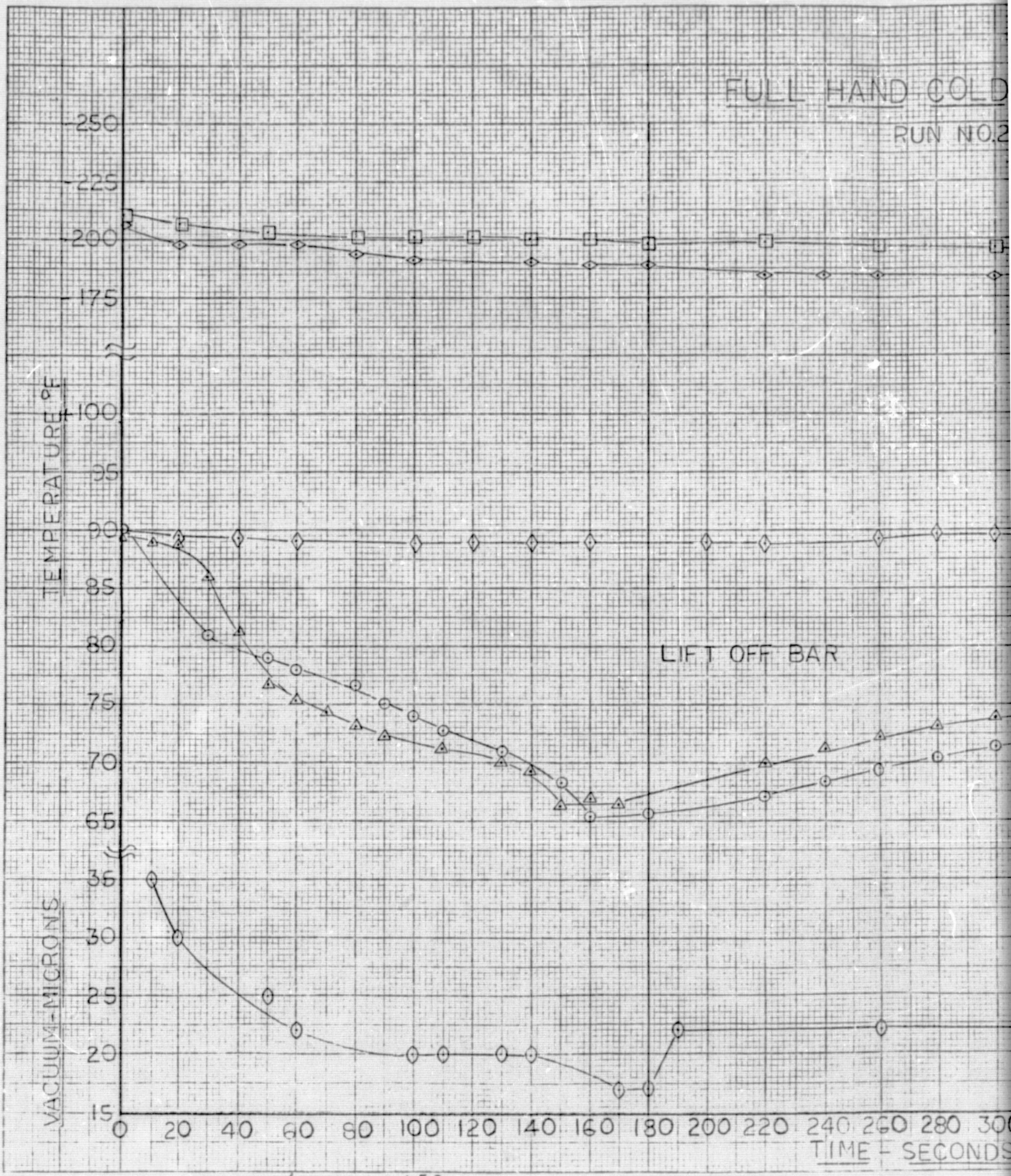


Figure 78

1/7/76


FULL HAND COLD
RUN NO.2
250
225
200
175
100
95
90
85
80
75
70
65
35
30
25
20
15
TEMPERATURE °F
VACUUM-MICRONS
LIFT OFF BAR
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
TIME - SECONDS

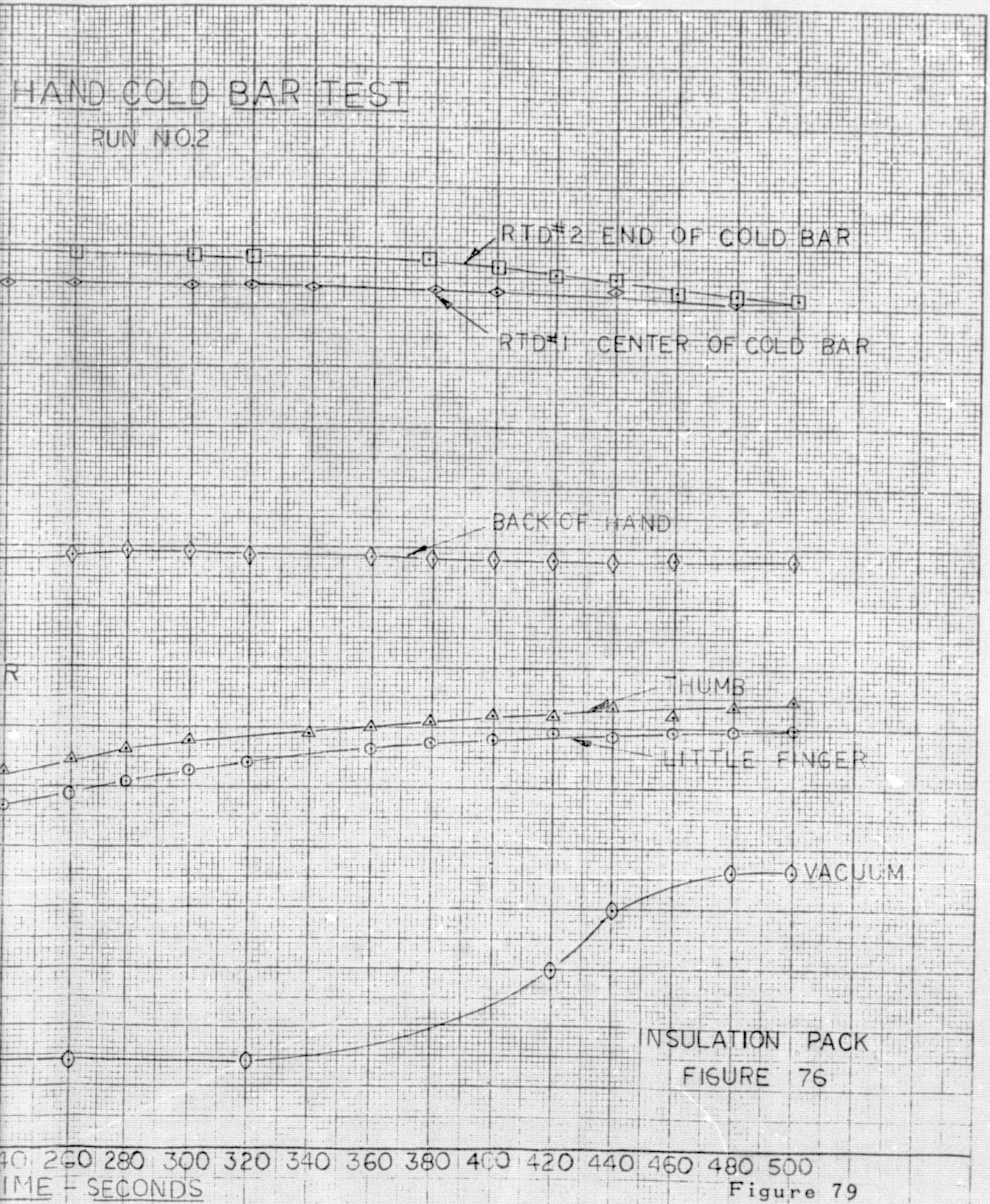


Figure 79

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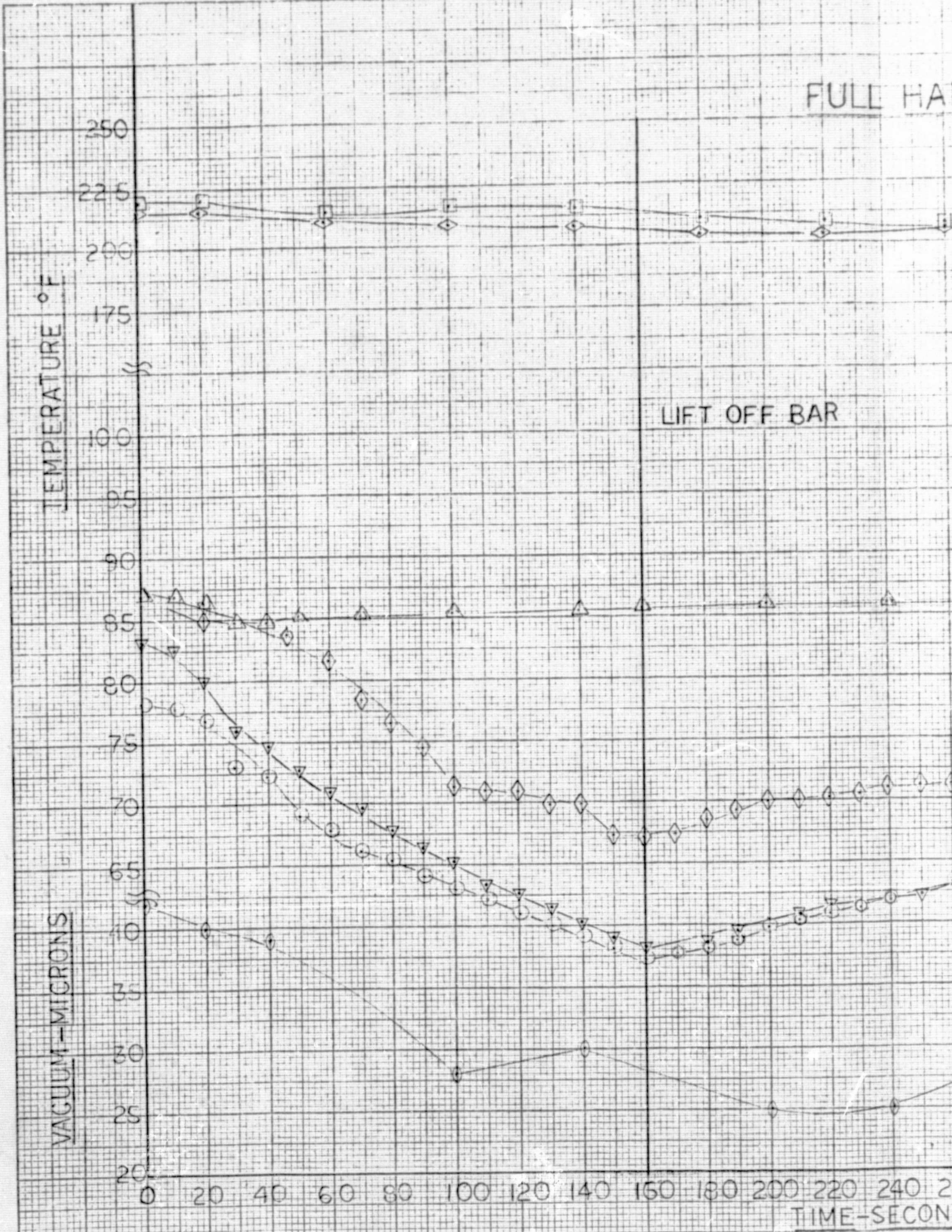
FULL HA
LIFT OFF BAR
TEMPERATURE °F
VACUUM-MICRONS
TIME-SECON
250
225
200
175
100
95
90
85
80
75
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120
140
160
180
200
220
240

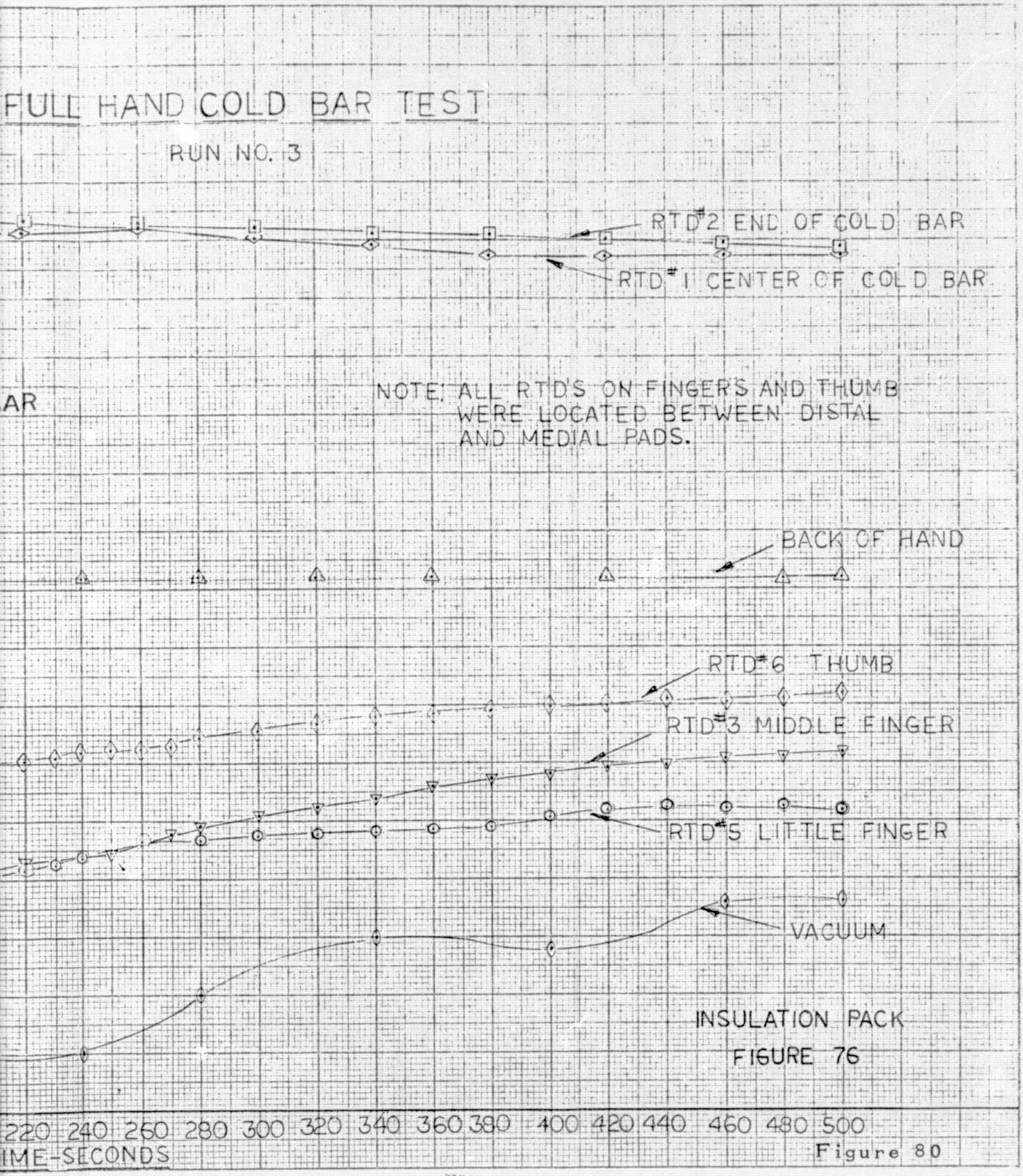

Figure 80

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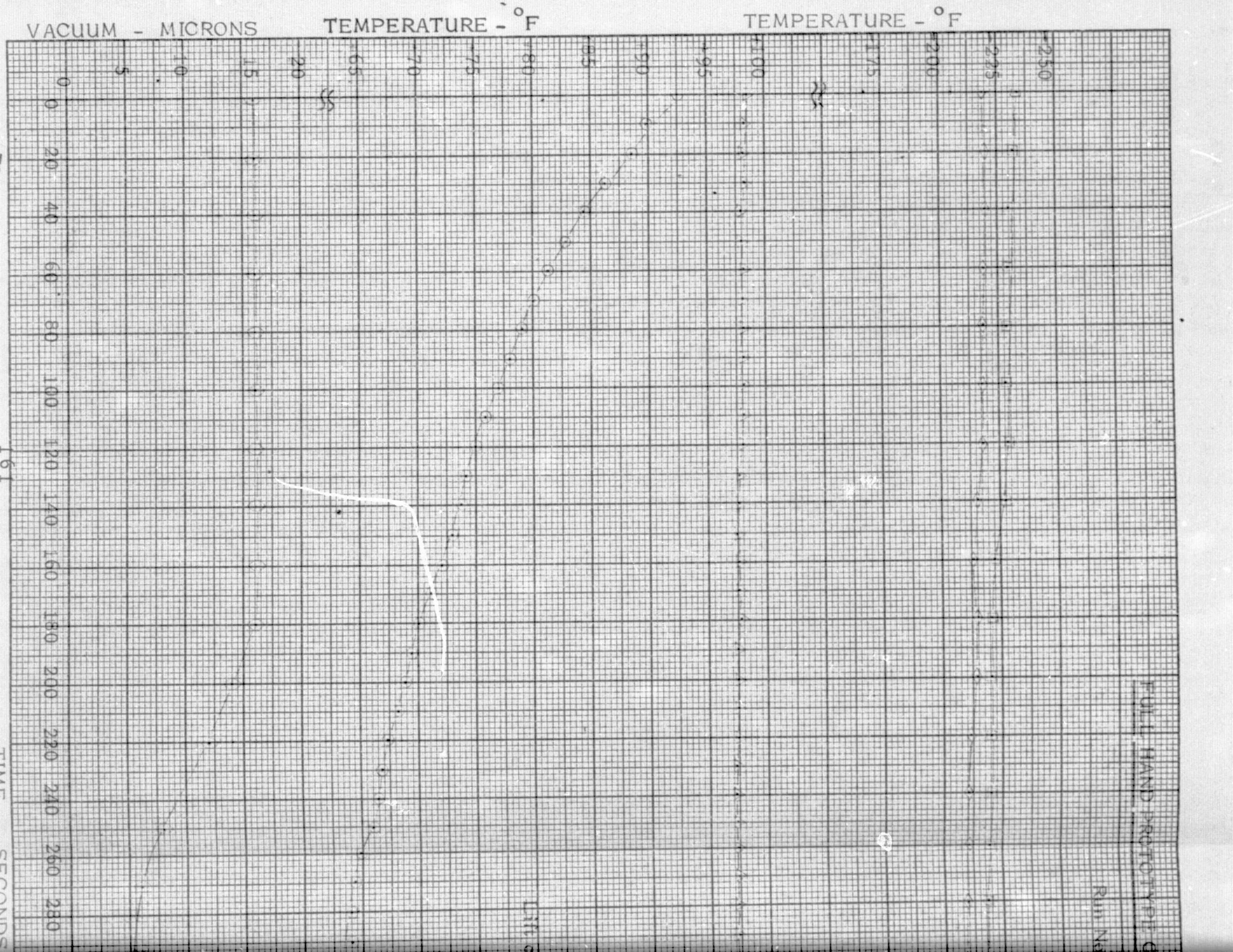


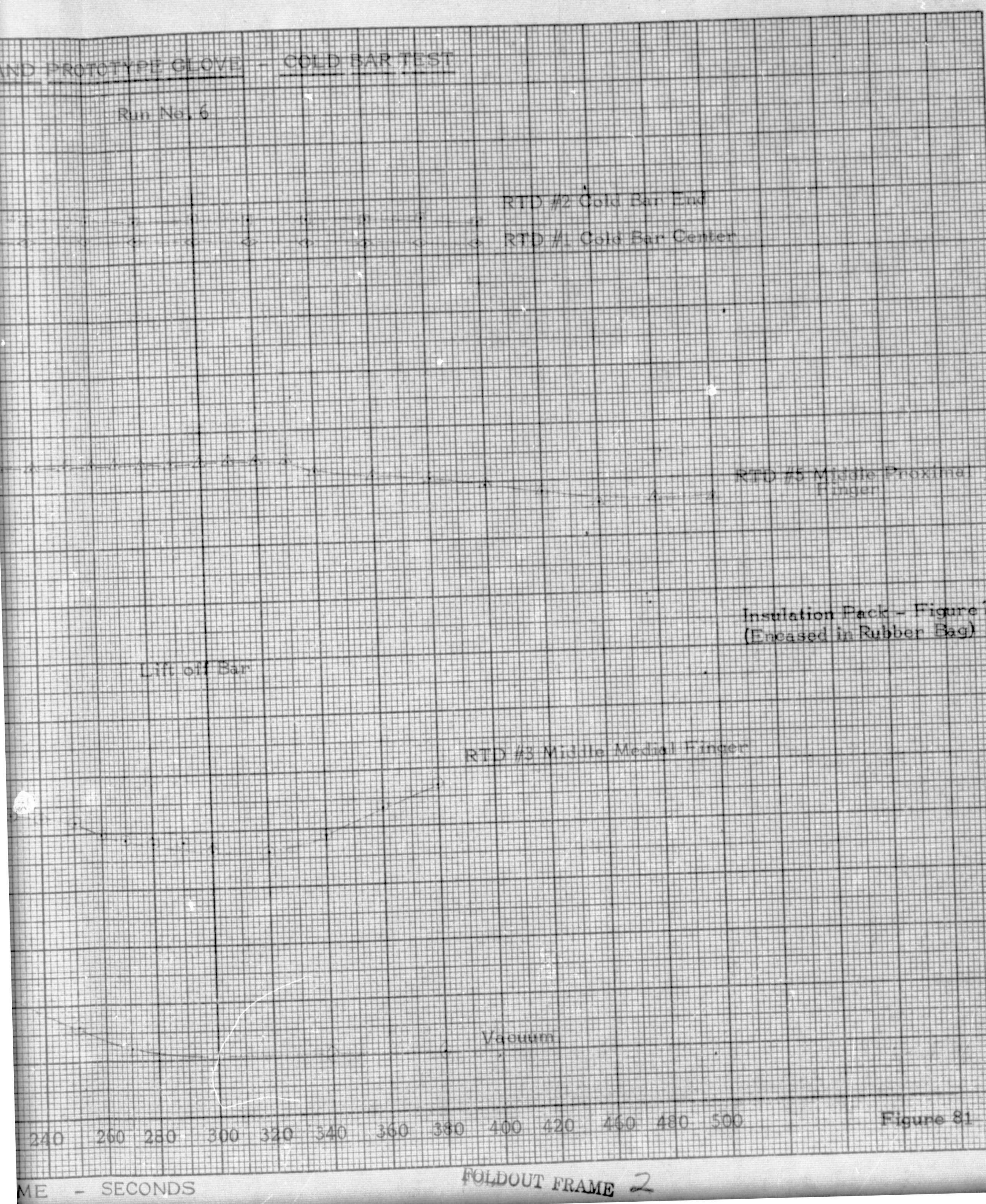


Figure 81

FOLDOUT FRAME 2

The tips of the fingers were very cold after 100 seconds into the test. Although earlier tests at ERA had indicated contact of the distal pads with a $1\frac{1}{2}$ inch diameter bar would not be made, the O.E.S. S/N 001 GFE glove configur tion caused the subject's fingertips to slightly touch the bar. This is due to the location of the GFE glove transverse reinforcing bar.

The fingers and thumb were instrumented at the base of the proximal pads for test no. 1. This was an error in that the reinforcing bar of the Kevlar outer glove would not allow the base of the fingers to touch the bar. The temperatures, though true values, do not indicate the low levels reached in the center and tips of the fingers. The hand was kept on the bar for 200 seconds at which time the fingertips were very cold. The test is considered to be a qualitative success though proper temperature measurements were not taken.

The insulation pad used for tests 1 and 2 consisted of insulation finger and thumb elements similar to those shown on Figure 76 which were "packaged" in an .008 inch thick latex glove with .090 inch thick trilock in the palm area, to permit good vacuum flow, and a 5/16 inch diameter brass tube for the vacuum connection. The thumb pad, of the initial insulation unit, did not cover the entire thumb so a separate single insulation unit was added to properly cover the thumb prior to test no. 3.

Due to the low temperatures of the fingertips encountered during test no. 1, it was decided to add approximately one half distal pad width active elements to each finger and the thumb prior to test no. 2.

The finger temperatures were measured between the medial and distal pads for test no. 2 and in subsequent tests. During test no. 2 at 180 seconds the middle finger was 61.2° F, the thumb was 66.5° F, and the little finger was 65.4° F.

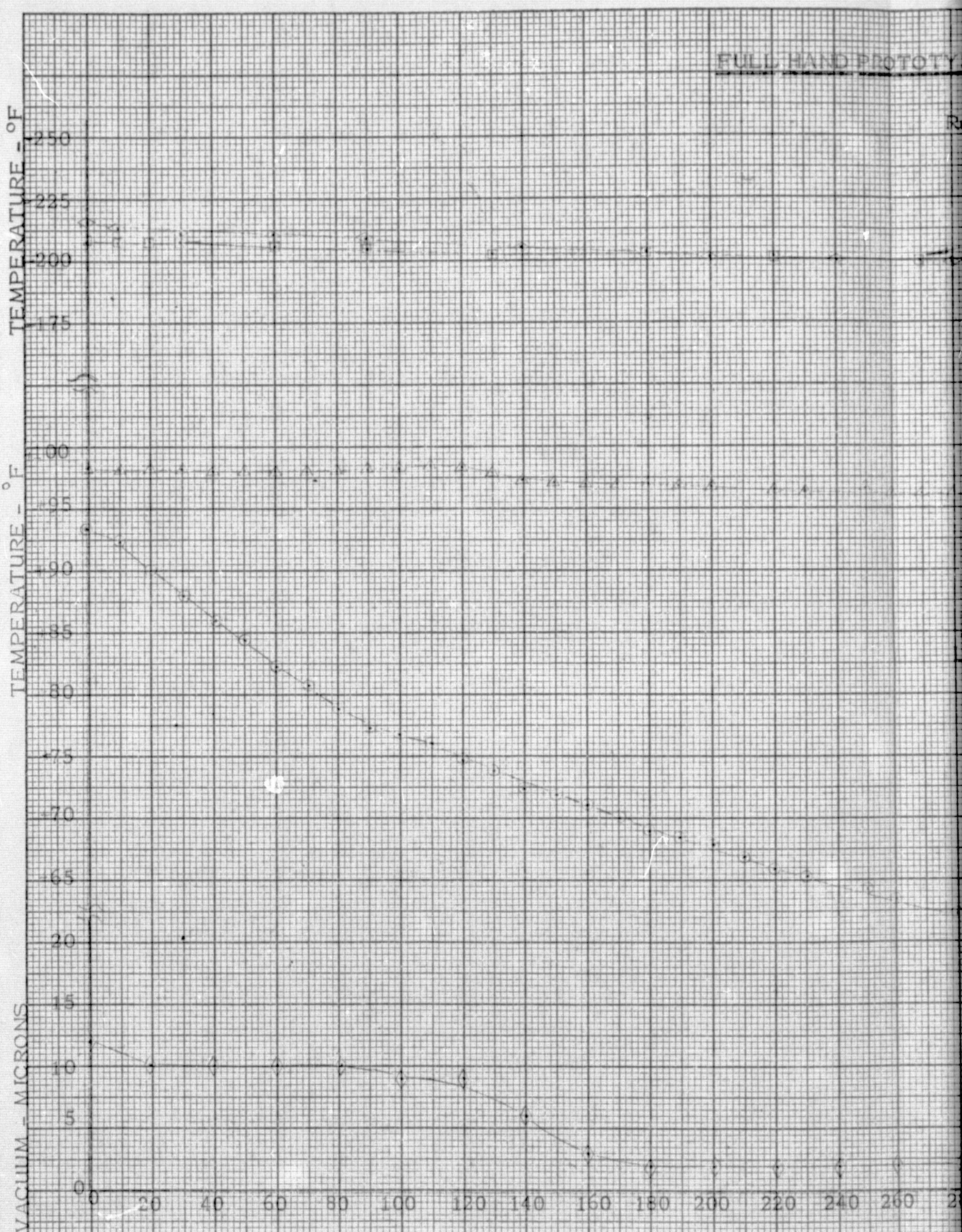
Test no. 3 was run $7\frac{1}{2}$ minutes after the completion of test no. 2 (due to an impending liquid nitrogen shortage) and with the same overall configuration and instrumentation as test no. 2. The finger temperatures at the start of the test were not fully recovered from the previous test (see Figure 79), therefore the end temperatures were lower than during the previous test. At 160 seconds the middle finger was 58.2° F, the thumb was 67.1° F, and the little finger was 57.4° F.

These three tests showed that the prototype active heating elements together with the chosen insulation pad design could provide adequate protection against the -200° F while gripping the $1\frac{1}{2}$ inch diameter bar for at least three minutes. The high vacuum pressures obtained during these tests, particularly test no. 2 wherein the hand had been adjacent to the insulation pack the longest and the gassing off from the materials was therefore the greatest, prevented the higher finger temperatures which would otherwise be available.

Two additional tests were made using the full glove assembly but testing only the middle finger on the cold bar. These tests were made in an effort to obtain lower vacuum pressures, since the MP-2 single finger insulation pack was used. The pull on the bar was reduced to three pounds for these tests. The vacuum pressures for test no. 6, Figure 81, ranged from 16 to 5 microns. The medial pad flexural and the proximal pad flexural areas were instrumented. Again the proximal temperature showed little change since the rea was not in contact with the cold bar. The medial pad flexural area was 70.0° F at 180 seconds and 63.3° F at 300 seconds.

Test no. 7 was a repeat of test no. 6 with resulting medial pad flexural area temperatures of 69.0° F at 180 seconds and 61.0° F at 300 seconds, Fig. 82

Tests nos. 4 and 5 were abortive due to incomplete positioning of the insulation pads.



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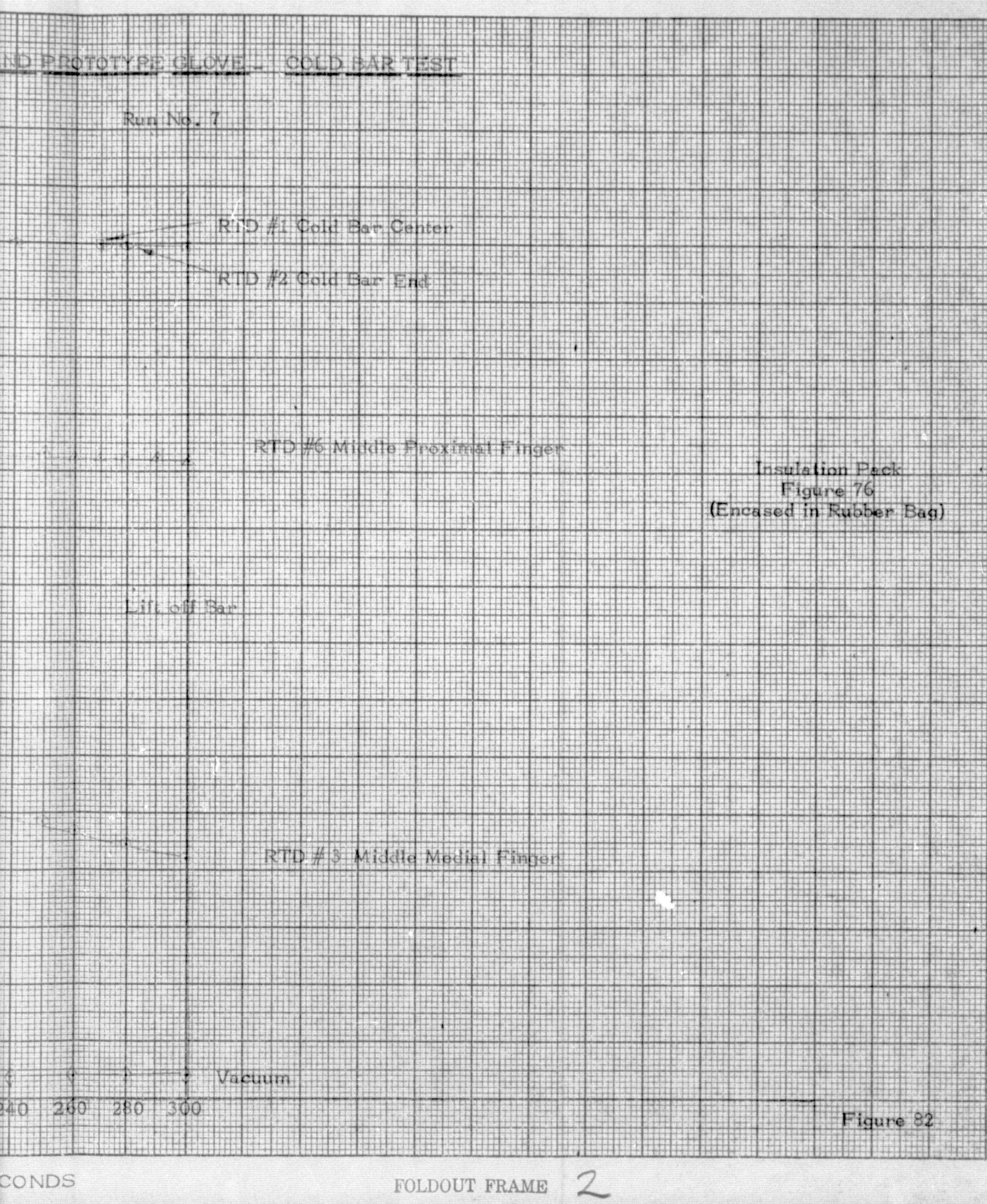

ND PROTOTYPE GLOVE - COLD BAR TEST
Run No. 7
RTD #1 Cold Bar Center
RTD #2 Cold Bar End
RTD #6 Middle Proximal Finger
Insulation Pack
Figure 76
(Encased in Rubber Bag)
Lift off Bar
RTD # 3 Middle Medial Finger
Vacuum
240
260
280
300
CONDS

Figure 82

Summary of the Acceptance Tests

Leak tests of the water injection system showed no leakage up to 40 psi sustained pressure. This is about one hundred percent higher than the operating pressures as supplied by the ERA furnished injector assembly.

The air leakage at 4.0 psig at 0.7 SCC is minimal and compares favorably with the NASA 10 SCC requirement on the RFQ.

The total weight of the glove proper is 289.2 grams or .638 pounds, (the final water injector system will have to be added, of course.) This compares favorably with the Schweickart (GFE) glove, 631.6 grams and the work glove (GFE) 643.1 grams.

Comfort and tactility are good but optimum comparisons cannot be made since the (GFE) outer Kevlar glove is too small for the best fit with ECHGS components, even for the subject used (smallest hand available).

The cold bar tests show that the bar can be held at -200^{o} F or colder for 180 seconds and even 300 seconds within safety and comfort limits.

The hot bar tests were not reconducted since the ERA vacuum system is limiting and since this system was tested at Houston with satisfactory cooling capabilities. The overcooling problem has been corrected by lowering the water flow and providing further adjustment capability in the demonstration injector pump. It is to be noted that the active heating elements of the ECHGS will also effectively reduce peak finger temperatures when the hot bar is held. Single finger tests showed capabilities within pain threshold limits for 180 seconds and beyond.

The ECHGS with the attendant water injection unit fulfills the contract requirements as outlined above.

Glove Adapter Assembly

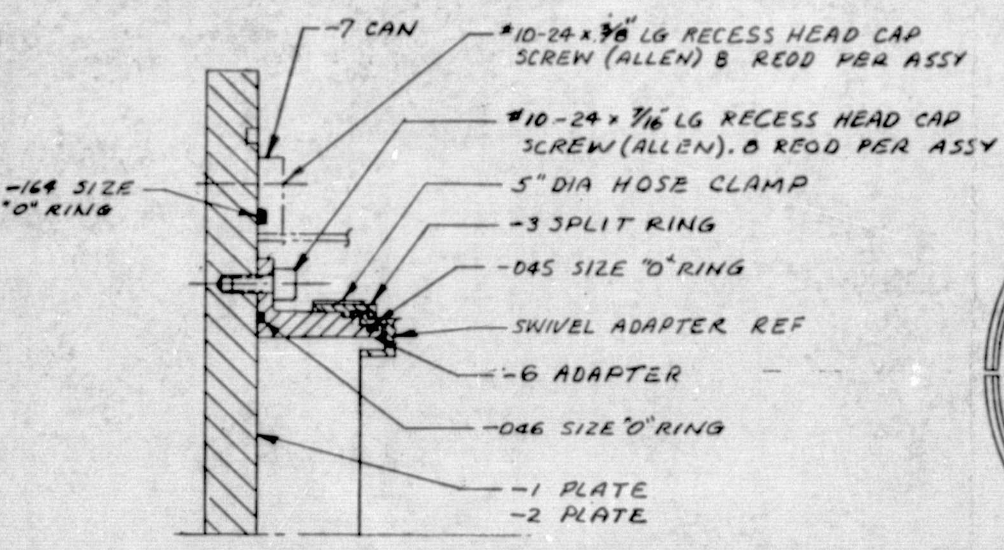
The Glove Adapter Assembly (Figures 83 and 84) was made to permit pressurization of the glove to any level up to atmospheric pressure. This is accomplished by adapting to the glove wrist ring with an "O" ring sealed end plate. Be reducing the pressure, as desired, in the main tank by use of a vacuum pump the atmospheric pressure provides the necessary differential pressure. When a very small vacuum line is used to evacuate the unit, there is no danger of exposing the hand to lower than atmospheric pressure due to glove failure.

The unit is used to pressure check the glove and to perform certain tests, such as flexure tests and limited tactility tests. Long term pressure tests can be conveniently made using the unit.

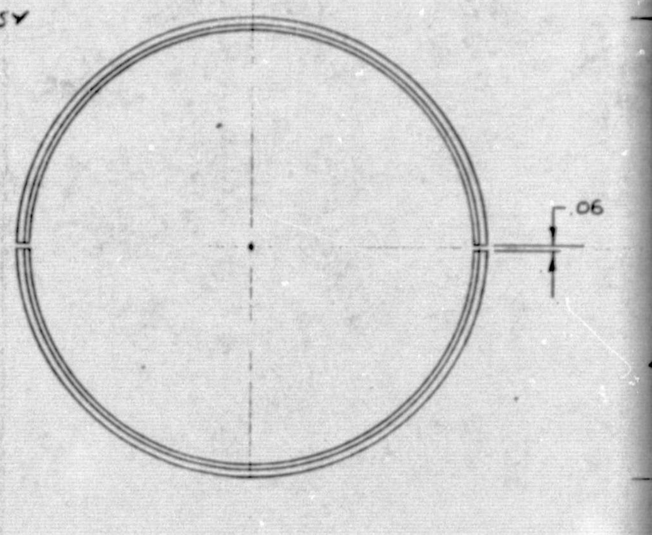
The Glove Adapter Assembly is being delivered with the ECHGS. In fact, the prototype glove and the final outer assembly of the ECHGS are packaged within the assembly for shipping. Storage at NASA of the outer assembly of the ECHGS within the Glove Adapter Assembly is suggested.

Inner Glove Assembly
Hand Tree

The inner glove assembly of the ECHGS has been packaged on a "hand tree" to provide support and protection for the active elements during storage. The finger positions are marked on the tree assembly and should be used as marked to prevent tearing or stretching of the glove. The plastic dust cover will prevent external damage to the active elements. It is strongly suggested that the inner glove assembly be stored on the hand tree provided and that handling be kept to a minimum unless the glove is to be used for tests.

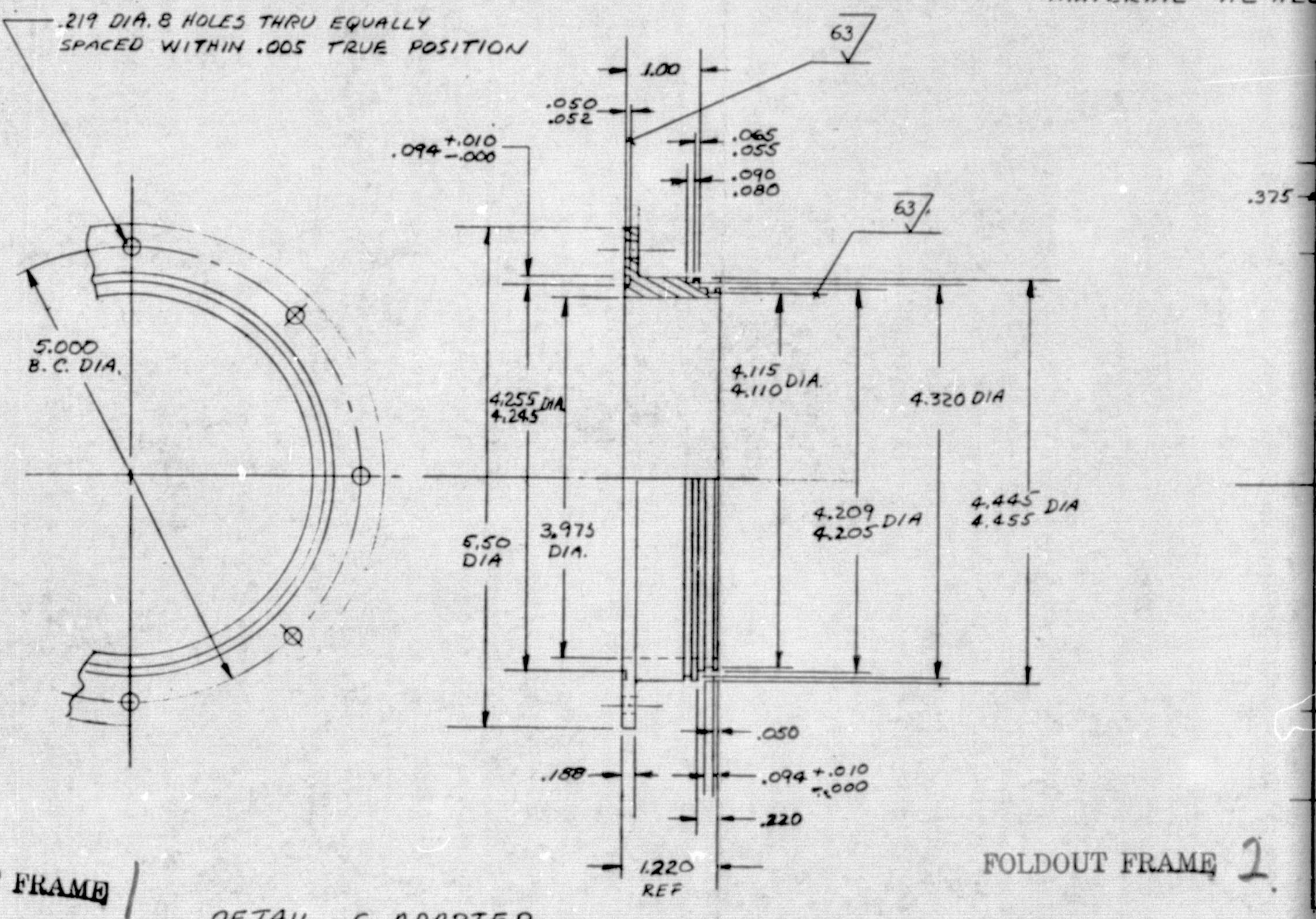


GLOVE ADAPTER ASSY



DETAIL -3 SPLIT

2 REQ'D
MATERIAL AL AL



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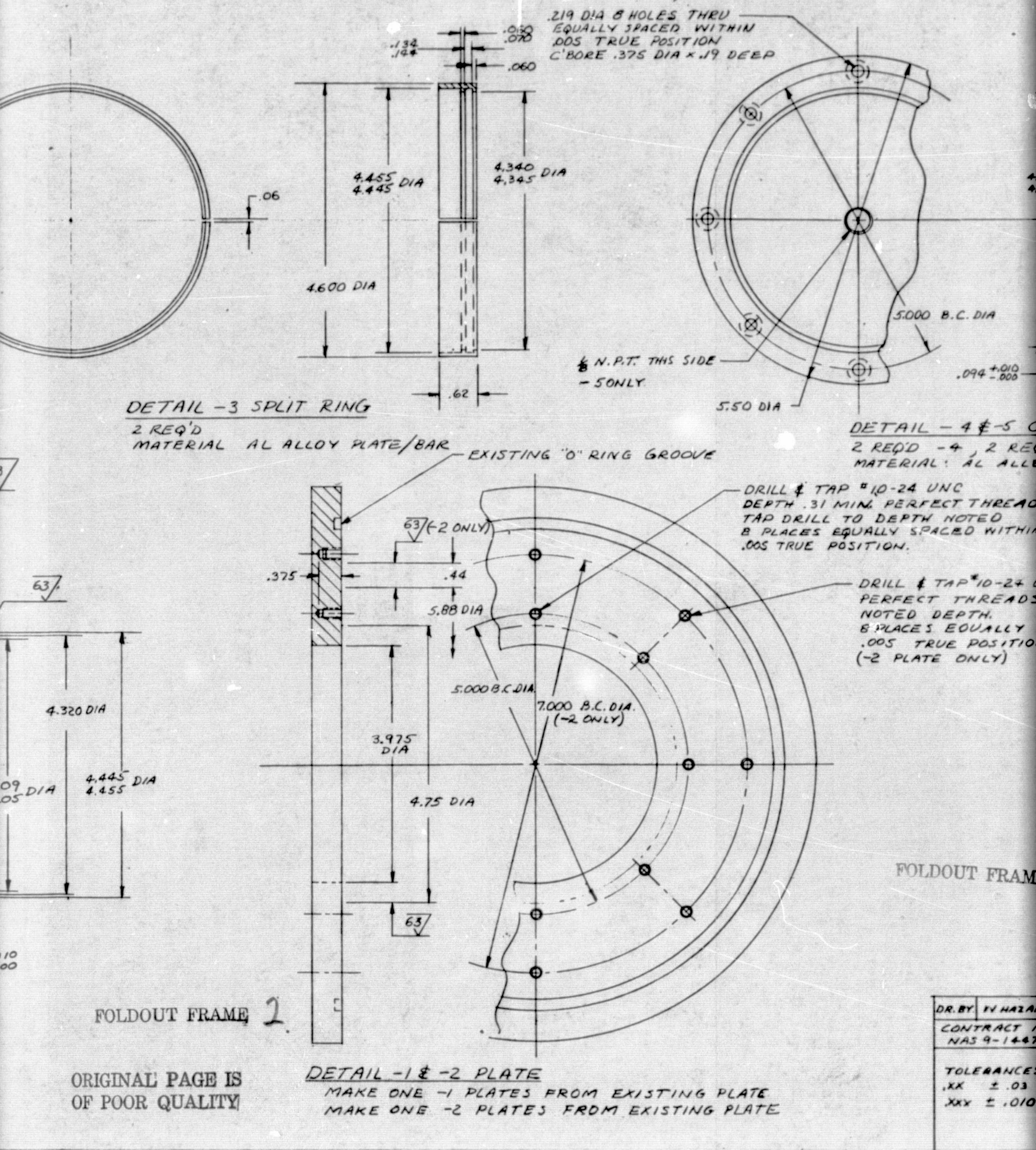
FOLDOUT FRAME 2

DETAIL -6 ADAPTER

2 REQ'D.
MATERIAL: AL. ALLOY PLATE/BAR



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FOLDOUT FRAME

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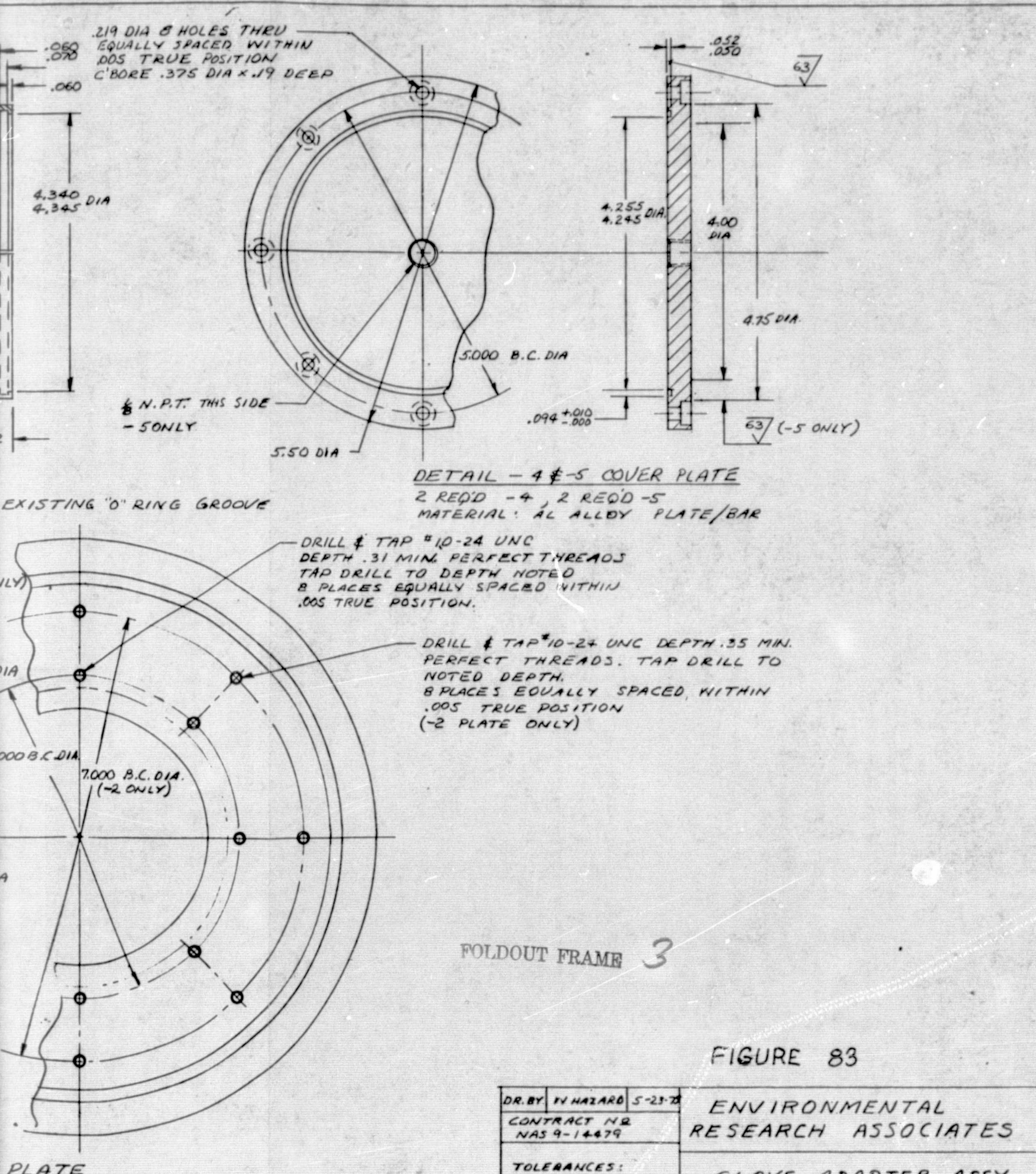

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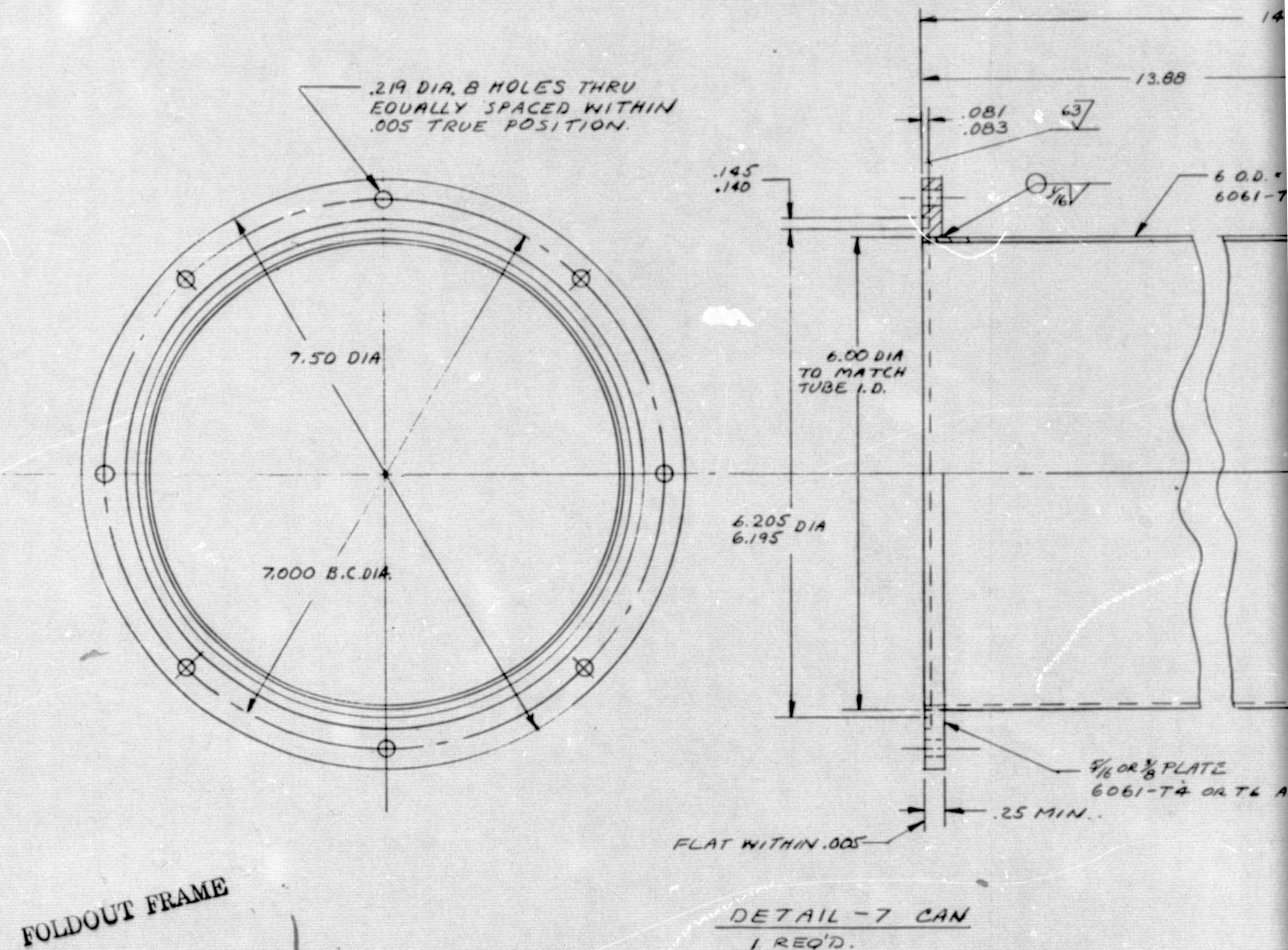
FIGURE 83

DR. BY W HAZARD 5-23-78	ENVIRONMENTAL RESEARCH ASSOCIATES
CONTRACT NO. NAS 9-14479	
TOLERANCES: .XX ± .03 .XXX ± .010	GLOVE ADAPTER ASSY
	SCALE - FULL SH. 1 OF 2



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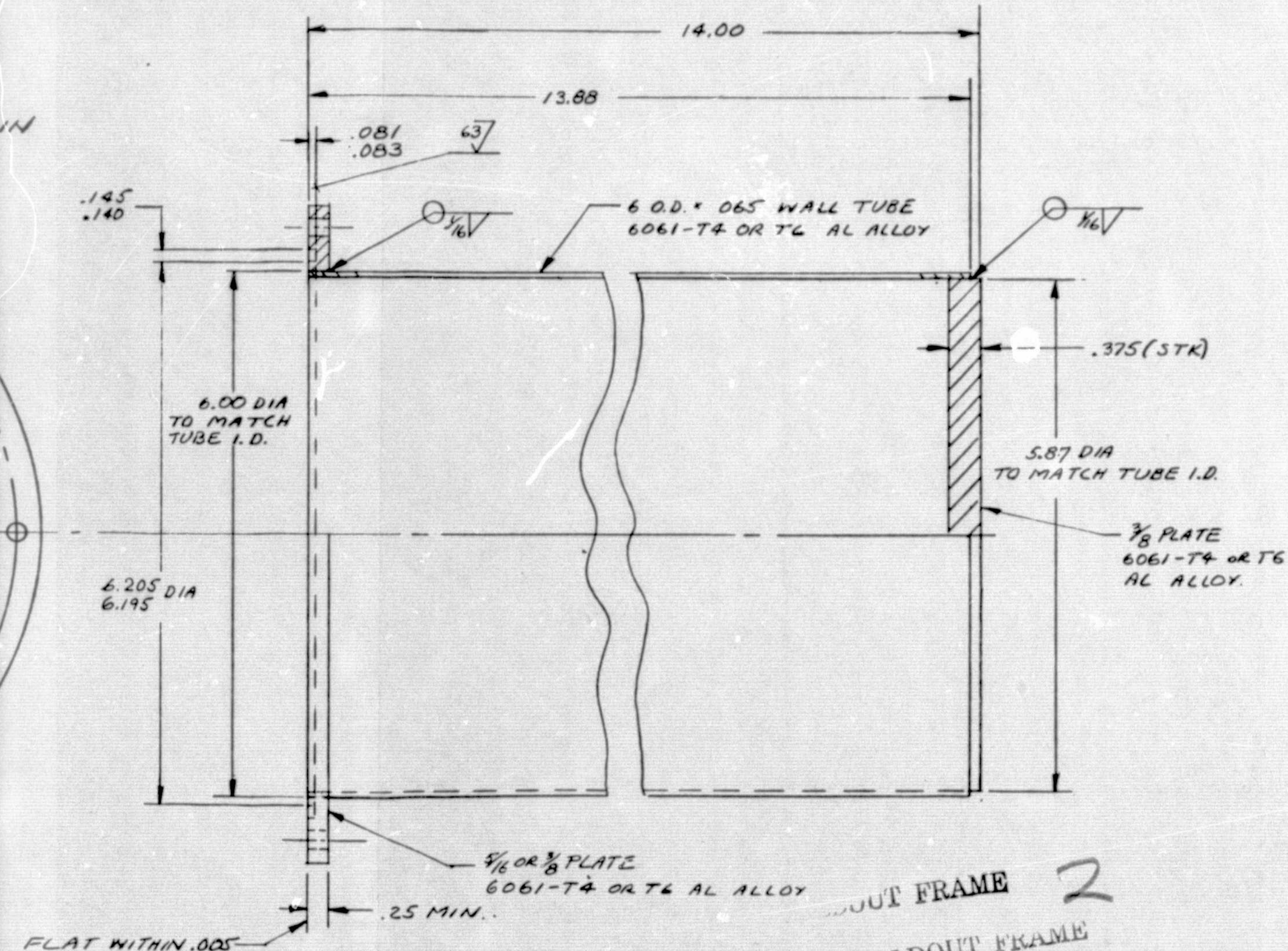

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DETAIL - 7 CAN

1 REQ'D.

FIGURE 84

DR. BY W. HAZARD 5-23-75	ENVIRONMENTAL RESEARCH ASSOCIATES
CONTRACT NO. NAS 9-14479	GLOVE ADAPTER ASSY
	SCALE - FULL SH 2 OF 2

References and Bibliography

1) "Anatomy Of The Human Body", Henry Gray, Edited by C. Mayo Goss, 1959

2) "Bioastronautics Data Handbook", Edited by Paul Webb, National Aeronautics and Space Administration, 1964

3) "Development of Techniques for the Evaluation of High Altitude Pressure Suits" - Wright Development Center - WADC Tech. Rept. 58-641 under Contract No. AF 33 (616)-3592.

4) "Emergency Evaporative Coolant Garment System/Liquid-Cooled Garment (EECGS/LCG), Part II" - Final Report, NASA Contract No. NAS-9-7207 by McDonnell Douglas Corp.

5) "Emergency Evaporative Coolant Garment System/Liquid-Cooled Garment (EECG/LCG), Pahse III" _ Final Report, NASA Contract No. NAS 9-10931 by McDonnell Douglas Corp.

6) "Evaluation and Comparison of Three Space Suit Assemblies" by R. L. Jones, NASA TN D-3482.

7) "Evaporative Cooling Garment System (ECGS), Part I" - Final Report, NASA Contract No. NAS 9-7202 by McDonnell Douglas Corp.

8) "Handbook of Chemistry and Physics", 49th Edition, Edited by Robert C. Weast, 1968

9) "Lunar Surface and Free Space Hazards Relating to Space Suit Design" by Jerry R. Goodman and Matthew I. Radnofsky, NASA Manned Spacecraft Center, as published in June 1965, The Journal of Environmental Sciences.

10) "Manual of Surgical Anatomy" Military Surgical Manuals, National Research Council, 1945.

11) "Medical Physiology", Edited by Philip Bard, 1956.

12) "Medical Physics" Edited by Otto Glasser, Vol I, 1955, Vol II, 1950 Vol III, 1960.

13) "Nonmetallic Materials Design Guidelines and Test Data Handbook", (NASA) MSC-NA-D-68-1, Rev. B.

14) "Study of the Thermal Processes for Man-In-Space", prepared under NASA Contract No. NAS -1015 by AiResearch Manufacturing Co., NASA report CR-216.

15) "Thermal Insulation Systems", NASA SP-5027.

APPENDIX A

OPERATION OF THE PROTOTYPE GLOVE WATER INJECTION SYSTEM

1.0 INTRODUCTION

This section outlines the operation of the water injection system for the ERA-ECHGS prototype glove that was tested at NASA-JSC in Houston, Texas during the month of July. A schematic diagram of the system is shown in Figure 36.

2.0 OPERATION

The injection system makes one complete cycle each time the round cam-knob is rotated 360 degrees. A cycle consists of three steps: 1) injection cylinder fills with water; 2) injection cylinder injects water into glove's cooling system; and 3) a short burst of air from the pressure tank clears all lines of water, thus preventing any ice plug from forming.

The detail of each step is as follows:

The first step occurs when valves two and four open. (Note: each valve is opened whenever its cam-follower rides a lobe on its cam. See Figure 8. Also, a "catch" in the rotation of the cam-knob occurs whenever any lobe is encountered by a cam-follower, and serves to indicate that a set of valves is about to open).. Valve two pressurizes the right-hand side of the master cylinder, pushing the plungers of both the master and injection cylinder out. Valve four allows water to flow from the water supply tank into the injection cylinder.

The second step occurs when valves five and one open. Valve five allows water to be injected into the glove's cooling system. Valve one pressurizes the left-hand side of the master cylinder, which pushes the plungers of both

the master and the injection cylinder in, injecting the water into the glove.

Step three occurs when valves three and six open. These valves allow air to flow from[s] the pressure tank through the water feed lines into the glove's cooling system. The air clears water from the lines, and prevents an ice plug from forming which would prevent any further water injections. After step three is complete the round cam-knob will rotate freely until the lobes on cams two and four are encountered again by their cam-followers, indicated by a "catch" in the rotation of the knob. This completes one cycle. The injection system is then ready for step one, and another complete cycle.

3.0 DURATION OF EACH STEP

The duration of each step should be noted carefully so as to insure that a sufficient volume of water is injected during each cycle.

1) Step One. Valves two and four should remain open for approximately ten seconds or longer. This is to allow sufficient time for water to fill the injection cylinder.

2) Step Two. Valves one and five should remain open for approximately ten seconds or more, also. This allows time for all the water to be injected into the glove's cooling system.

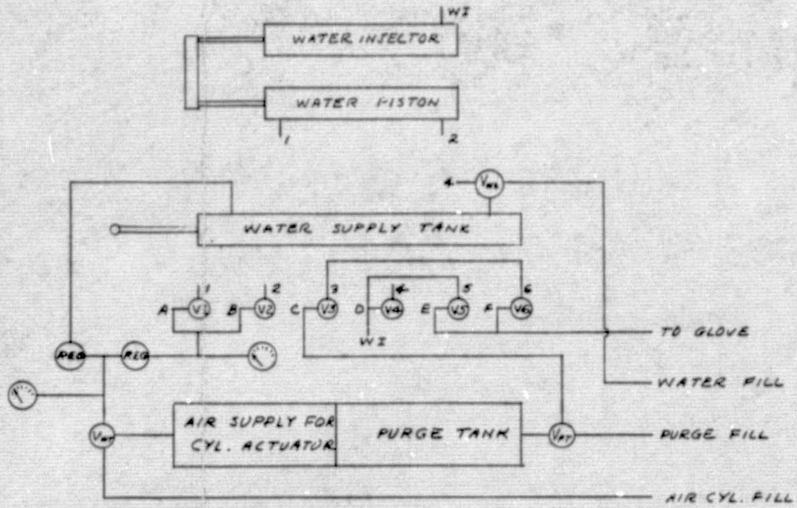
3) Step Three. Valves three and six should remain open <u>for as brief a period as possible</u>. The cam-knob should be turned very quickly past the open position for these valves. This is to prevent too much air from entering the space-vacuum chamber, and to prevent the pressure tank from completely emptying.

4.0 FILLING PROCEDURE

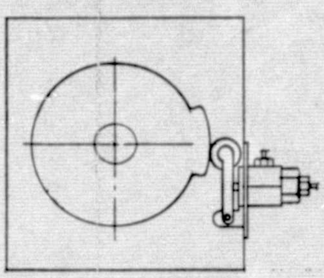
1) Step One. Rotate "Hand Crank" clockwise to horizontalposition, flip valves Vwt and Vpt to "fill position" (toggles opposed to each other), open shut off for valve Vws (screw driver slot).

2) Step Two. Place water fill hase (at end of umbilical) in supply of cold, boiled (degassed), distilled water, extend plunger which then fills water supply tank. While holding plunger to full extended position, close off valve Vws.

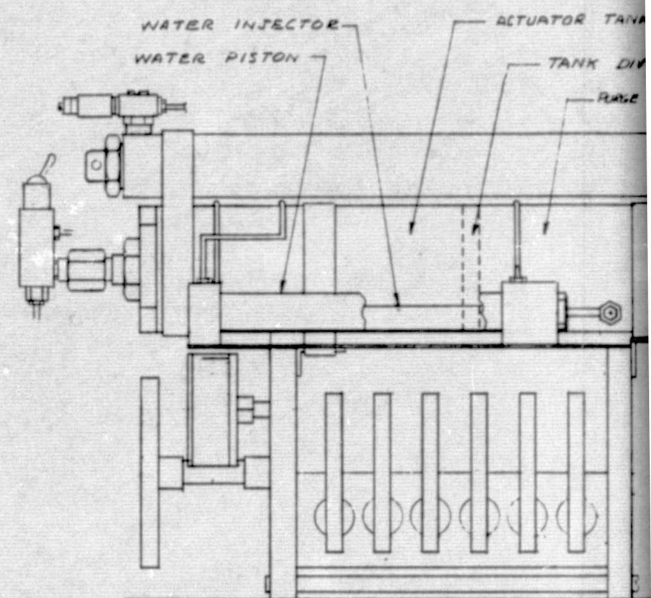
3) Step Three. Fill air storage tank via air disconnect fitting at end of umbilical, pressurize to 200 psi as shown on large pressure gauge attached to regulator, small pressure gauge should read slightly under 40 psi, flip toggles to "store position" (toggles Vwt and Vpt towards each other), disconnect umbilical from air supply. System is now ready for use.



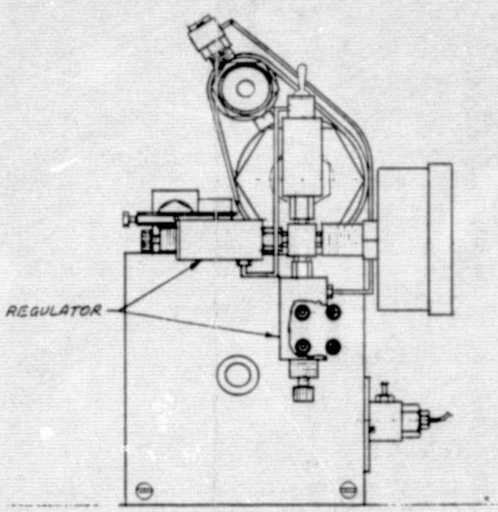
PLUMBING SCHEMATIC

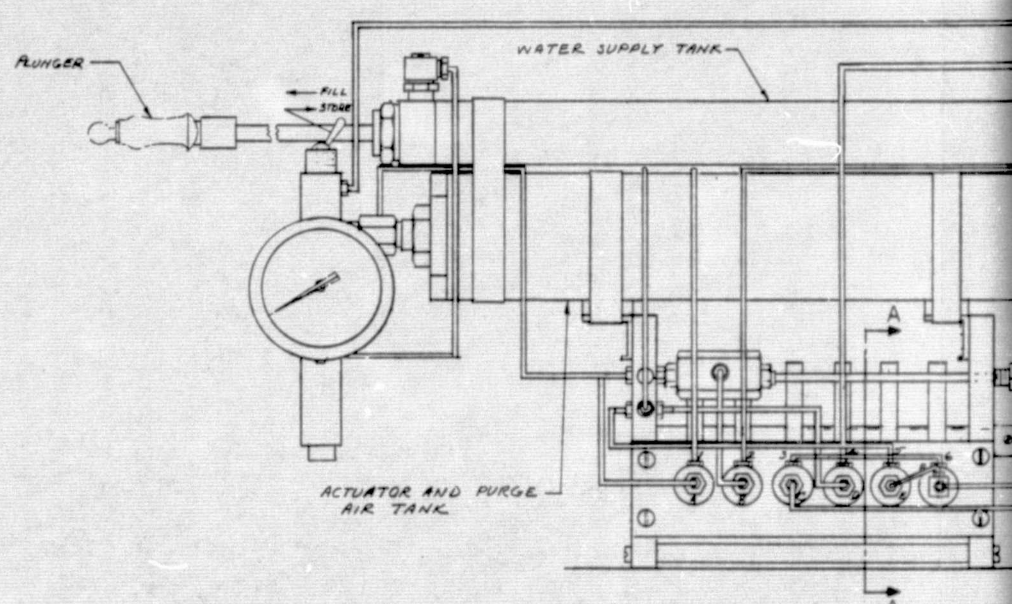


SECTION A-A

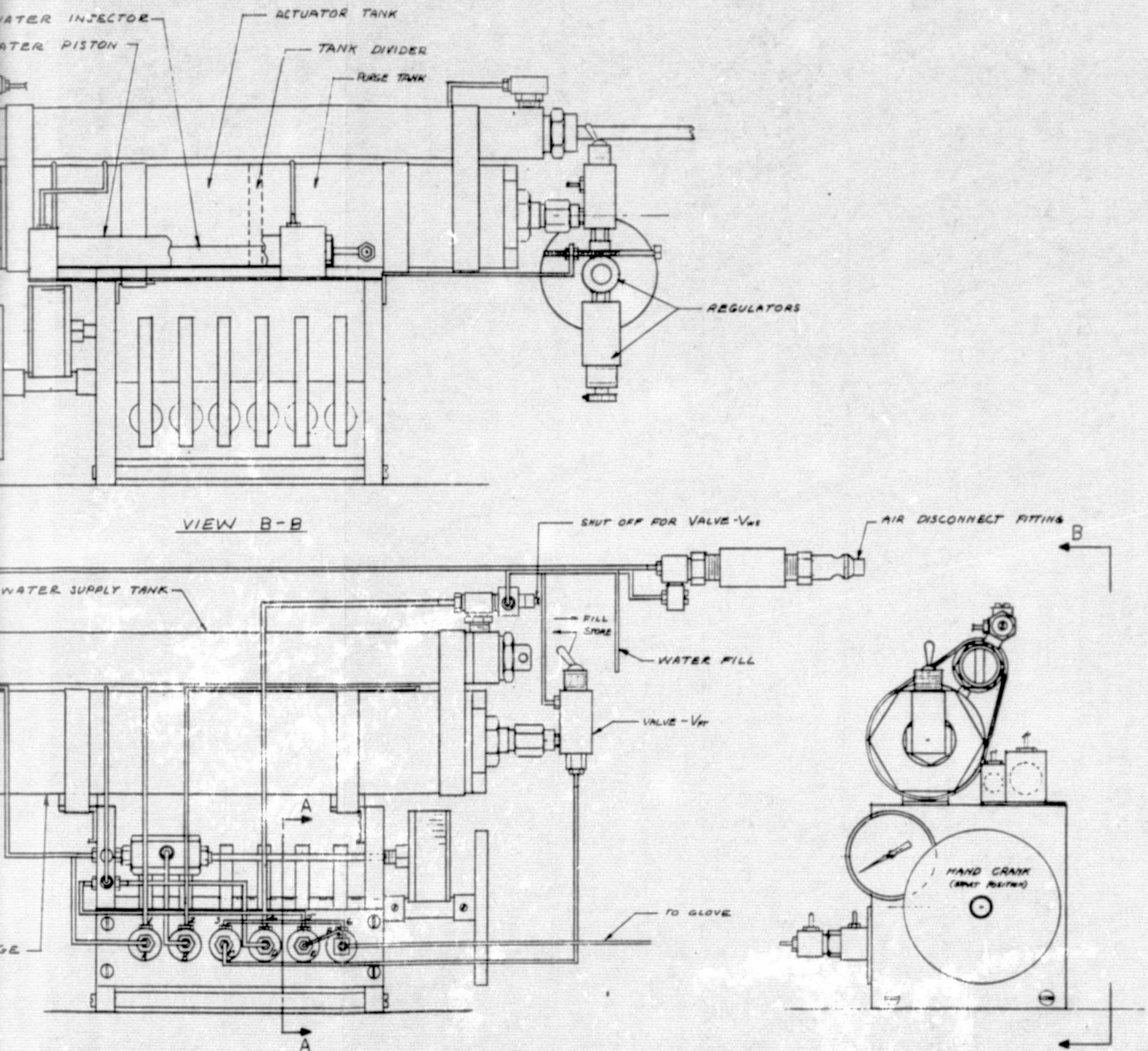


VIEW B-B





FOLDOUT FRAME 1



FOLDOUT FRAME 2

CONTRACT NO			-E. R. A.-
DR BY	P HUGHES	1-10-76	GLOVE WATER INJECTOR DEVICE
CHK BY			
APPR	[signature]	1-22-76	
DATE			FIG. 85
			SCALE-NONE SHT 1